STABILIZATION OF BLAST FURNACE SLAG AND FLY ASH USING LIME AND RBI GRADE 81

A REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Civil Engineering

By

SUSHANTA BHUYAN

DEPARTMENT OF CIVIL ENGINEERING
NIT ROURKELA

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Under the Guidance of

Prof. S.P.SINGH

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA
2010

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**STABILIZATION OF BLAST FURNACE SLAG AND FLY ASH USING LIME AND RBI GRADE 81**" submitted by **SUSHANTA BHUYAN** in partial fulfillments for the requirements for the degree of Bachelor of Technology 2009-10 in Civil Engineering at **National Institute of Technology, Rourkela** is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other University / Institute for the award of any Certificate.

Date: 12-05-2010

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Date: 12-05-2010 **SUSHANTA BHUYAN**

ABSTRACT

The objective of the project is to use industrial wastes in place of natural soil in the construction of road and highway after increasing its strength, stability and durability by the method of stabilization using lime and RBI grade 81.Traditionally soil, stone aggregates, sand, bitumen, cement etc. are used for road construction. Natural materials being exhaustible in nature, its quantity is declining gradually. Huge amount of soil is used in the construction of road and highway but sufficient amount of soil of required quality is not available easily. For that reason large amount of trees are being cut which cause deforestation, soil erosion and loss of fertile soil which hampers in the agricultural productivity. Also, cost of extracting good quality of natural material is increasing. Concerned about this, the scientists are looking for alternative materials for highway construction, and industrial waste product is one such category. If these materials can be suitably utilized in highway construction, the pollution and disposal problems may be partly reduced. Stabilization is the method used in this project to increase the inherent strength of wastes like fly ash and blast furnace slag (BFS) using lime and RBI grade 81. The present project work aims at evaluating the effectiveness of lime and RBI Grade 81 in stabilizing the waste products like fly ash and BFS mixes and its suitability in road construction. This will save the natural soil in addition to addressing the disposal problems of industrial solid wastes in a great way. Fly ash was collected from the captive power plant (CPP-II) and BFS from the dump pad of Rourkela steel plant (RSP). The collected samples were oven dried and mixed thoroughly to get homogeneity in the Geotechnical Engineering laboratory. The samples were then kept in different air tight container for the project work. Samples were then prepared mixing fly ash and BFS with different percentage at an interval of 10% and standard proctor test was carried out to get optimum moisture content (OMC) and maximum dry density (MDD). Stabilized samples were prepared mixing fly ash and BFS with different percentage at an interval of 10% and with stabilizing agent lime and RBI grade 81 with increasing percentage as 0%, 2%, 4%, 6%, and 8%. The samples were then subjected to unconfined compressive test after 7, 14, 28 and 60 days of curing. The above samples were prepared using constant volume mould by static compression method.

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CHAPTER 1

INTRODUCTION

Since the outset of the industrial revolution the greatest challenge before the processing and manufacturing industries is the disposal of the residual waste products. Waste products which are generally toxic, ignitable, corrosive or reactive pose serious health and environmental consequences. Thus disposal of industrial wastes is a measure issue of the present generation. This measure issue requires an effective, economic and environment friend method to combat the disposal of the residual industrial waste products. One of the common and feasible ways to utilize these waste products is to go for construction of roads, highways and embankments. If these materials can be suitably utilized in construction of roads, highways and embankments then the pollution problem caused by the industrial wastes can be greatly reduced. Huge amount of soil is used in the construction of roads and highways but sufficient amount of soil of required quality is not available easily. For that reason large amount of trees are being cut which cause deforestation, soil erosion and loss of fertile soil which hampers in the agricultural productivity. Also, cost of extracting good quality of natural material is increasing. These industrial wastes which are used as a substitute for natural soil in the construction not only solve the problems of disposal and environmental pollution but also help to preserve the natural soil. The challenge for the present and future of road construction is the appropriate implementation of waste or industrial by-products as constructing materials. This will provide a number of significant benefits to the constructing industry as well as to the country as a whole by conservation of natural resources, by reduction of volume of waste to landfills, by lowering the cost of construction materials, by lowering waste disposal costs, and the last but not the least by promoting a ‘clean and green’ image. The industrial wastes used in this project are blast furnace slag (BFS) and fly ash. Stabilization is the method used in this project to increase the inherent strength of industrial wastes blast furnace slag (BFS) and fly ash using lime and RBI grade 81. The present project work aims at evaluating the effectiveness of lime and RBI Grade 81 in stabilizing the waste products BFS and fly ash and its suitability in road construction. Fly ash was collected from the captive power plant (CPP-II) and BFS from the dump pad of Rourkela steel plant (RSP). The collected samples were oven dried and mixed thoroughly to get homogeneity in the Geotechnical Engineering laboratory. The samples were then kept in different air tight container. The geotechnical properties of BFS and fly ash were then found out through laboratory experiments. Specific gravity test was performed for both BFS and fly ash. Standard proctor test was also conducted to obtain optimum moisture content (OMC) and maximum dry density (MDD) of fly ash. BFS, fly ash, lime and RBI grade 81 were studied under scanning electron microscope (SEM) to get the magnified photographs of the particles.

Samples were then prepared mixing BFS and fly ash with different percentage at an interval of 10% and standard proctor test was carried out to get optimum moisture content (OMC) and maximum dry density (MDD). Stabilized samples were prepared mixing BFS and fly ash with different percentage at an interval of 10% and with stabilizing agent lime and RBI grade 81 with increasing percentage as 2%, 4%, 6%, and 8%. The above samples were prepared using constant volume mould by static compression method. The samples were then subjected to unconfined compressive test after 7, 14, 28 and 60 days of curing.

CHAPTER 2

LITERATURE REVIEW

2.1 Industrial waste products: An Overview

Industrial waste is a type of waste produced by processing and manufacturing industries, factories, mills and mines. It has existed since the industrial revolution. Much industrial waste is neither hazardous nor toxic, such as waste fiber produced by agriculture and logging. Industrial waste consists of toxic waste, chemical waste, industrial solid waste and municipal solid waste. Table1 provides an idea about different waste product and their possible usage.

Table2.1. Possible usage of industrial waste products in highway construction

SL.NO.	WASTE PRODUCT	SOURCE	POSSIBLE USAGE
1.	Fly ash	Thermal power station	Bulk fill, filler in bituminous mix, artificial aggregates
2.	Blast furnace slag	Steel industry	Base/ Sub-base material, Binder in soil stabilization (ground slag)
3.	Construction and demolition waste	Construction industry	Base/ Sub-base material, bulk-fill, recycling
4.	Colliery spoil	Coal mining	Bulk-fill
5.	Spent oil shale	Petrochemical industry	Bulk-fill
6.	Foundry sands	Foundry industry	Bulk-fill, filler for concrete, crack-relief layer
7.	Mill tailings	Mineral processing industry industry	Granular base/sub-base, aggregates in bituminous mix, bulk fill
8.	Cement kiln dust	Cement industry	Stabilization of base, binder in bituminous mix
9.	Used engine oil	Automobile industry	Air entraining of concrete
10.	Marble dust	Marble industry	Filler in bituminous mix

2.1.1 Fly Ash: An Overview

Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. When mixed with lime and water the fly ash forms a cementitious compound with properties very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of cement in the concrete, providing some distinct quality advantages. The concrete is denser resulting in a tighter, smoother surface with less bleeding. Fly ash concrete offers a distinct architectural benefit with improved textural consistency and sharper detail. Fly Ash is also known as Coal Ash, Pulverized Flue Ash, and Pozzolona. Fly ash closely resembles volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Those cements were made near the small Italian town of Pozzuoli - which later gave its name to the term "pozzolan." A pozzolan is a siliceous or siliceous / aluminous material that, when mixed with lime and water, forms a cementitious compound. Fly ash is the best known, and one of the most commonly used, pozzolans in the world. Instead of volcanoes, today's fly ash comes primarily from coal-fired electricity generating power plants. These power plants grind coal to powder fineness before it is burned. Fly ash - the mineral residue produced by burning coal - is captured from the power plant's exhaust gases and collected for use. Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. The difference between fly ash and Portland cement becomes apparent under a microscope. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete.

2.1.2 Blast Furnace Slag (BFS): An Overview

Blast furnace slag (BFS) is a nonmetallic co product produced in the process of iron production. It consists primarily of silicates, aluminosilicates, and calcium-alumina-silicates. The molten slag, which absorbs much of the sulfur from the charge, comprises about 20 percent by mass of iron production. Fig2.1 presents a general schematic, which depicts the blast furnace feed stocks and the production of blast furnace co products (iron and slag).

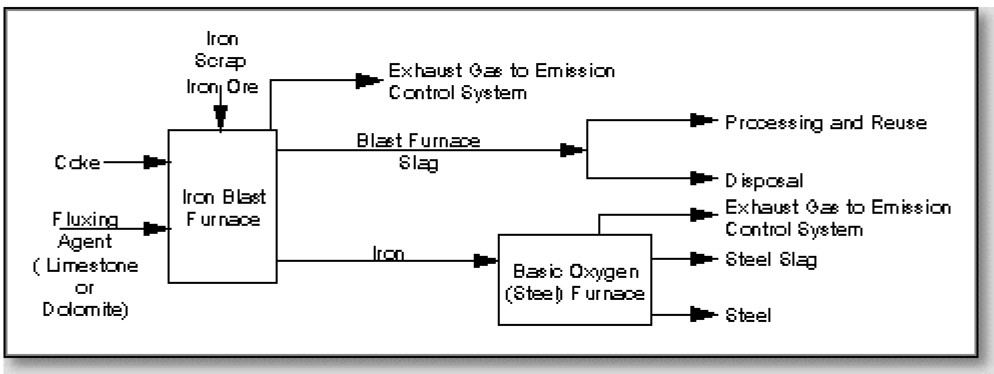

Fig2.1 Schematic diagram of production of BFS.

Different forms of slag product are produced depending on the method used to cool the molten slag. These products include air-cooled blast furnace slag (ACBFS), expanded or foamed slag, pelletized slag, and granulated blast furnace slag.

1.) Air-Cooled Blast Furnace Slag (ACBFS): If the liquid slag is poured into beds and slowly cooled under ambient conditions, a crystalline structure is formed, and a hard, lump slag is produced, which can subsequently be crushed and screened.

2.) Expanded or Foamed Blast Furnace Slag(EBFS): If the molten slag is cooled and solidified by adding controlled quantities of water, air, or steam, the process of cooling and solidification can be accelerated, increasing the cellular nature of the slag and producing a lightweight expanded or foamed product. Foamed slag is distinguishable from air-cooled blast furnace slag by its relatively high porosity and low bulk density.

3.) Pelletized Blast Furnace Slag (PBFS): If the molten slag is cooled and solidified with water and air quenched in a spinning drum, pellets, rather than a solid mass, can be produced. By controlling the process, the pellets can be made more crystalline, which is beneficial for aggregate use, or more vitrified (glassy), which is more desirable in cementitious applications. More rapid quenching results in greater vitrification and less crystallization.

4.) Granulated Blast Furnace Slag (GBFS): If the molten slag is cooled and solidified by rapid water quenching to a glassy state, little or no crystallization occurs. This process results in the formation of sand size (or frit-like) fragments, usually with some friable clinker like material. The physical structure and gradation of granulated slag depend on the chemical composition of the slag, its temperature at the time of water quenching, and the method of production. When crushed or milled to very fine cement-sized particles, ground granulated blast furnace slag (GGBFS) has cementitious properties, which make a suitable partial replacement for or additive to Portland cement

2.2 Lime: An Overview

Calcium oxide (CaO), commonly known as quicklime, is a widely used chemical compound. It is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminium oxide and iron oxide.

Lime is produced by calcinations of limestone in a lime kiln at temperatures above 1,000° C. Calcium carbonate (CaCO3) is converted into calcium oxide (CaO) and carbon dioxide (CO2). Active calcium oxide is highly reactive. In finely ground burnt lime a high level (80-90%) of calcium oxide guarantees good stabilization reaction in the soil, favourable water reduction in the soil and a temperature increase upon slaking.

Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix. Most lime used for soil treatment is “high calcium” lime, which contains no more than 5 percent magnesium oxide or hydroxide.

On some occasions, however, "dolomitic" lime is used. Dolomitic lime contains 35 to 46 percent magnesium oxide or hydroxide. Dolomitic lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction. Sometimes the term “lime” is used to describe agricultural lime which is generally finely ground limestone, a useful soil amendment but not chemically active enough to lead to soil stabilization.“Lime” is also sometimes used to describe byproducts of the lime manufacturing process (such as lime kiln dust), which, although they contain some reactive lime, generally have only a fraction of the oxide or hydroxide content of the manufactured product. In this manual, “lime” means quicklime, hydrated lime, or hydrated lime slurry.

The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures (Figure 1). With proper design and construction techniques, lime treatment chemically transforms unstable soils into usable materials. Indeed, the structural strength of lime-stabilized soils can be factored into pavement designs.

Lime, either alone or in combination with other materials, can be used to treat a range of soil types. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good soil for stabilization. Soils containing significant amounts of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime and/or special construction procedures.

Lime has a number of effects when added into soil which can be generally categorized as soil drying, soil modification, and soil stabilization.

(i) Soil drying is a rapid decrease in soil moisture content due to the chemical reaction between water and quicklime and the addition of dry material into a moist soil.

(ii) Modification effects include: reduction in soil plasticity, increase in optimum moisture content, decrease in maximum dry density, improved compact aibility, reduction of the soil’s capacity to swell and shrink, and improved strength and stability after compaction. These effects generally take place within a short time period after the lime is introduced – typically 1 to 48 hours – and are more pronounced in soils with sizable clay content, but may or may not be permanent.

(iii) Lime stabilization occurs in soils containing a suitable amount of clay and the proper mineralogy to produce long-term strength; and permanent reduction in shrinking, swelling, and soil plasticity with adequate durability to resist the detrimental effects of cyclic freezing and thawing and prolonged soaking. Lime stabilization occurs over a longer time period of "curing." The effects of lime stabilization are typically measured after 28 days or longer, but can be accelerated by increasing the soil temperature during the curing period. A soil that is lime stabilized also experiences the effects of soil drying and modification.

2.3 RBI Grade 81: An Overview

RBI Grade 81 Natural Soil Stabilizer is a unique and innovative product that was developed for the stabilization of a wide spectrum of soils in an efficient, least-cost manner. RBI Grade 81 is an environmental friendly, inorganic, hydration activated powder-based stabilizer that reacts with soil particles to create layers that are interconnected through a complex inter-particle framework.

RBI Grade 81's ability to react with a wide range of soil types and under different soil conditions eliminates the requirement for multiple stabilizers for a given project. Results of many applications both in-situ and in laboratories have consistently proven that the success of the resultant stabilized layer is not jeopardized through changes in the soil type. Clay, silt, sand and gravel based soils can all be stabilized with a single product. RBI Grade 81 was obtained from the company named Legend Surface Developers Private Limited who signed a manufacturing license agreement on an exclusive basis in India with Road Building International in 2007.

History and Development of RBI Grade 81:

1990. South African scientists set out to develop a unique, environmentally friendly comprehensive and irreversible soil stabilizer for road construction.

1998. RBI Grade 81, after 10 years of R&D was granted a South African patent.

2001. First production facility set up in Israel, with production capacity of 30 ton/hour.

2002. Standards Institute of Israel and the ministry of environment award the facility with a Green Label for the product's environmental benefits.

2003. Road Building International sells its rights of RBI Grade 81 to Anyway Solutions in certain territories, retaining exclusive jurisdictions to 73 countries around the world.

2003. RBI Grade 81 granted an International patent that went uncontested and deemed to offer “a novel and unique technology.”

2004. Road Building International sign manufacturing License Agreement with Readers in the United Kingdom, a division of Langley Holding PLC, a multinational engineering group, rated by HSBC as one of the UK's top 250 companies, providing capital equipment technologies worldwide.

2005. Portugal, the first EU country to specify RBI Grade 81 in a government tender.

2006. Mapei, one of Europe's largest producers of auxiliary materials for building and industry, signs a manufacturing license agreement with Road Building International on an exclusive basis in Italy.

2006. European Investment Bank confirms co-operation for future implementation of RBI in infrastructure and environmental projects.

2007. Government of Romania sanction the use of RBI Grade 81 for governmental projects.

2007. Legend Surface Developers Private Limited signs a manufacturing license agreement on an exclusive basis in India with Road Building International.

2007. RBI Grade 81 internationally secures its place as the most state-of-the-art technology in road construction and pavement layer design through its ability to drastically reduce the associated economic and financial costs of road construction, and due to its environmental benefits, thereby aligning itself to the requirements of European Procurement Law.

2.4 Soil Stabilization: An Overview

The soil stabilization means the improvement of stability or bearing power of the soil by the use of controlled compaction, proportioning and/or the addition of suitable admixture or stabilizers.

Basic principles of soil stabilization:

1. Evaluating the properties of given soil.
2. Deciding the lacking property of soil and choose effective and economical method of soil stabilization.
3. Designing the stabilized soil mix for intended stability and durability values.

Need for soil stabilization:

1. Limited financial resources to provide a complete network road system to build in conventional method.
2. Effective utilization of locally available soils and other suitable stabilizing agents.
3. Encouraging the use of industrial wastages in building low cost construction of roads.

Methods of soil stabilization:

1. Mechanical stabilization
2. Soil cement stabilization
3. Soil lime stabilization
4. Soil bitumen stabilization
5. Lime fly ash stabilization
6. Lime fly ash bound macadam
7. RBI Grade 81 fly ash stabilization

2.5 Problem Statement

The purpose of the project is to use industrial wastes blast furnace slag (BFS) and fly ash collected from Rourkela steel plant in place of natural soil in the construction of road and highway after increasing its strength, bearing capacity, volume stability and durability by the method of stabilization using lime and RBI grade 81.

The present project work aims at evaluating the effectiveness of lime and RBI Grade 81 in stabilizing the waste products BFS and fly ash and its suitability in road construction.

The key objectives can be enumerated as:

i. Characterization of blast furnace slag (BFS) and fly ash.
ii. Evaluating the effectiveness of lime and RBI grade 81 in stabilizing BFS and fly ash.

2.6 Experimental Setups

2.6.1 Standard Proctor Test (IS 2720 Part VII 1980/87)

The standard proctor test was developed by **R.R.Proctor** (1933) for the construction of earth fill dams in the state of California.

The standard proctor test equipment consists of the following:

1. Cylindrical metal mould, having an internal diameter of 10 cm, an internal effective height of 12.75 cm and an effective volume of 1000 ml.
2. Detachable base plate.
3. Collar 5 cm in effective height.
4. Rammer 2.5 kg in mass falling through a height of 30.5 cm.

The test consists in compacting soil at various water contents in the mould, in three equal layers, each layer being given 25 blows of the 2.5 kg rammer dropped from a height of 30.5 cm. The dry density obtained in each test is determined by knowing the mass of the compacted soil and its water content. The compactive energy used for this test is 6065 kg cm per 100 ml of soil.

About 2.5 kg of oven dried soil passing through 4.75 mm sieve is then taken and thoroughly mixed with water. The quantity of water to be added initially depends upon the probable optimum water content for the soil. The initial water content is taken about 4% for the used samples of fly ash. The empty mould attached with the base plate is weighted without collar. The collar is then attached to the mould. The mixed and matured soil is placed in the mould and compacted by giving 25 blows of the rammer uniformly distributed over the surface, such that the compacted height of the soil is about 1/3 the height of the mould. The second and the third layers are similarly compacted, each layer being given 25 blows. The last layer should not project more than 6 mm into the collar. The collar is removed and the top layer is trimmed off to make it level with the top of mould.

The weight of the mould, base plate and the compacted soil is taken. A representative sample is taken from three different layers of the mould, one from the top layer, other from the middle section and the third from the bottom section of the mould, and kept for water content determination. The bulk density and the corresponding dry density for the compacted soil are calculated from the following relations:

$$\rho = M/V \text{ (g/cc); and}$$

$$\rho_d = \rho / (1+w) \text{ (g/cc);}$$

Where, ρ = bulk density of the soil (g/cc),

ρ_d = dry density of the soil (g/cc),

M = mass of the wet compacted specimen (g),

w = water content (ratio),

V = volume of the mould, 1000 ml.

The compacted soil is taken out of the mould and remixed with raised water content (by 4 %). After allowing mixing and maturing, the soil is compacted in the mould in three layers again and the corresponding dry density and water content is determined. The test is repeated with increasing water contents, and the corresponding dry density obtained is thus determined. A compaction curve is plotted between the water content as abscissa and the corresponding dry densities as ordinates. The dry density goes on increasing till the maximum density is reached. This density is called maximum dry density (MDD) and the corresponding moisture content is called optimum moisture content (OMC).

2.6.2 Unconfined Compressive Test (IS 2720 Part X 1980/87)

The unconfined compression test is a special case of triaxial compression test in which $\sigma2=\sigma3=0$. The cell pressure in the triaxial cell is also called the confining pressure. Due to the absence of such a confining pressure, the uniaxial test is called the unconfined compression test. The cylindrical specimen of soil is subjected to major principal stress $\sigma1$ till the specimen fails due to shearing along a critical plane of failure.

In its simplest form, the apparatus consists of a small load frame fitted with a proving ring to measure the vertical stress applied to the soil specimen.

The deformation of the sample is measured with the help of a separate dial gauge. The ends of the cylindrical specimen are hollowed in the form of cone. The cone seatings reduce the tendency of the specimen to become barrel shaped by reducing end-restraints. During the test, load versus deformation readings are taken and a graph is plotted. When a brittle failure occurs, the proving ring dial indicates a definite maximum load which drops rapidly with the further increase of strain. In the plastic failure, no definite maximum load is indicated. In such a case, the load corresponding to 20% strain is arbitrarily taken as the failure load.

CHAPTER 3
EXPERIMENTAL PROGRAMME

3.1 Introduction

The collected industrial waste BFS and fly ash were characterized in the geo-technical laboratory. The specific gravity test was performed for both of them. Standard proctor test was performed for fly ash and OMC and MDD were calculated. The grain size analysis was also done for both BFS and fly ash. The standard proctor test was also done for various compositions of BFS and fly ash at an interval of 10% and their respective OMC and MDD were calculated. Stabilized samples were prepared using BFS and fly ash mixes at an interval of 10% and using stabilizing agents lime and RBI grade 81 at an increasing percentage of 2%, 4%, 6% and 8%. Unconfined compressive test was conducted for the stabilized samples after curing the samples with wax for 7, 14, 28 and 60 days. Then the respective unconfined compressive strengths were calculated for different compositions.

3.2 Materials Used

3.2.1 Fly ash: Fly ash was collected from the captive power plant (CPP-II) of Rourkela steel plant (RSP). Fly ash samples were well dried and mixed thoroughly to bring homogeneity. These were stored in air tight container for subsequent use.

3.2.2 Blast furnace slag (BFS): BFS was collected from the dump pad of Rourkela steel plant (RSP). BFS samples were well dried and mixed thoroughly to bring homogeneity. Then the samples were sieved through 20 mm sieve. These sieved samples were stored in air tight container for subsequent use.

3.2.3 Lime: Lime is a form of quicklime (calcium oxide- CaO), hydrated lime (calcium hydroxide- $Ca[OH]_2$), or lime slurry can be used to treat soils. Lime was brought from market and was kept in air tight polythene bags.

3.2.4 RBI Grade 81: RBI Grade 81 Natural Soil Stabilizer is a unique and innovative product that was developed for the stabilization of a wide spectrum of soils in an efficient, least-cost manner. It was brought from a company named legend surface developer.

3.3 Sample preparation:

The stabilized samples were prepared using constant mould of internal diameter 5cm and height 10cm by static compression method. The stabilized samples were prepared at their respective OMC and MDD with different composition of BFS and fly ash at an interval of 10% and with stabilizing agents lime and RBI grade 81 with increasing percentage as 2%, 4%, 6% and 8%. Two samples for each composition were prepared. The stabilized samples were cured using wax and were kept for 7, 14, 28 and 60 days in the humidity chamber. The unconfined compressive test was performed after 7, 14, 28 and 60 day of curing.

Photo3.1. View of stabilized soil samples

Photo3.2. Testing of stabilized soil samples

3.4 Test performed:

Initially standard proctor test was performed to get the OMC and MDD of fly ash and also specific gravity test was performed for both fly ash and BFS. The OMC and MDD of fly ash were found out to be 40.1% and 1.08 gm/cm^3 respectively. The specific gravity of fly ash and BFS were found out to be 2.51 and 2.78 respectively. Standard proctor test was performed for samples mixed with different percentage composition of fly ash and BFS at an interval of 10% to find out OMC and MDD. Stabilized samples were prepared mixing fly ash and BFS with different percentage at an interval of 10% and with stabilizing agent lime and RBI grade 81 with increasing percentage as 0%, 2%, 4%, 6%, and 8%. The samples were then subjected to unconfined compressive test after 7, 14, 28 and 60 days of curing.

3.5 Experimental results

3.5.1 Characterization of BFS and fly ash

Table3.1. Physical properties of fly ash and BFS

PHYSICAL PARAMETERS	FLY ASH	BFS
colour	Blackish green	Brown
shape	rounded	Sub rounded to angular
Specific gravity , G	2.51	2.78
Maximum dry density(MDD) in g/cm^3	1.08	X
Optimum moisture content(OMC)	40.1%	X
Grain size distribution (%)		
Silt and clay	89	0.023
Fine sand	11	3.723
Medium sand	0	13.013
Coarse sand	0	17.96
Fine gravel	0	63.45
Coefficient of uniformity($C_u=D_{60}/D_{10}$)	3.16	5.9
Coefficient of curvature($C_c=D_{30}^2/(D_{60}*D_{10})$)	1.04	1.66
Plasticity index	Non plastic	Non plastic
Void ratio i.Maximum ii.Minimum	X	 0.68 0.35

The arrangement of particles in the fly ash specimen is viewed at a magnification of 5000 and 2000 at 15 kV under the scanning electron microscope in a pressure of 50 Pa. The photograph of the magnified view is as follows:

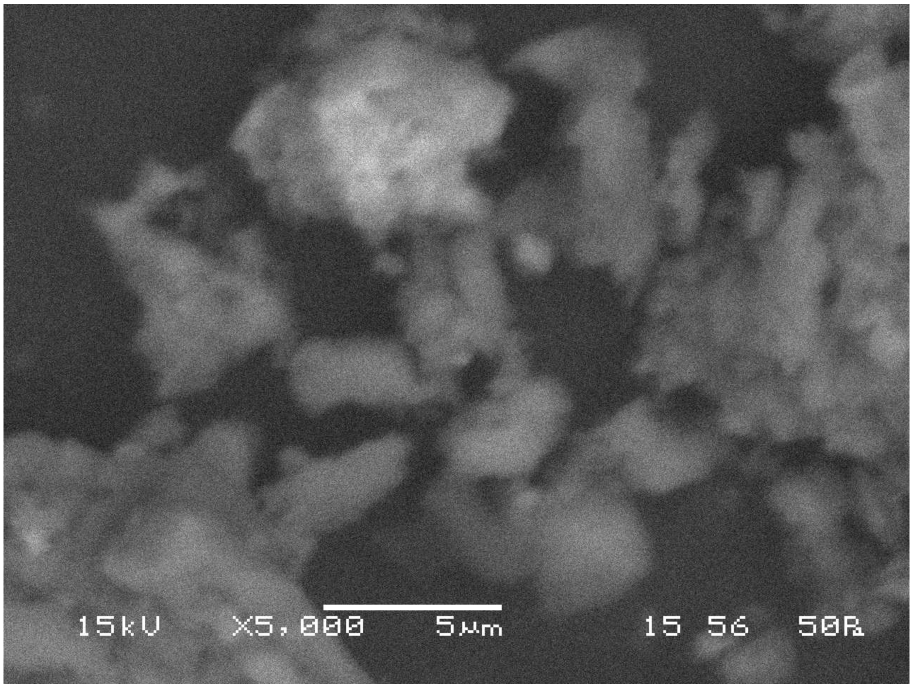

Photo3.3. Particle arrangement (SEM) at 5000M: Fly ash

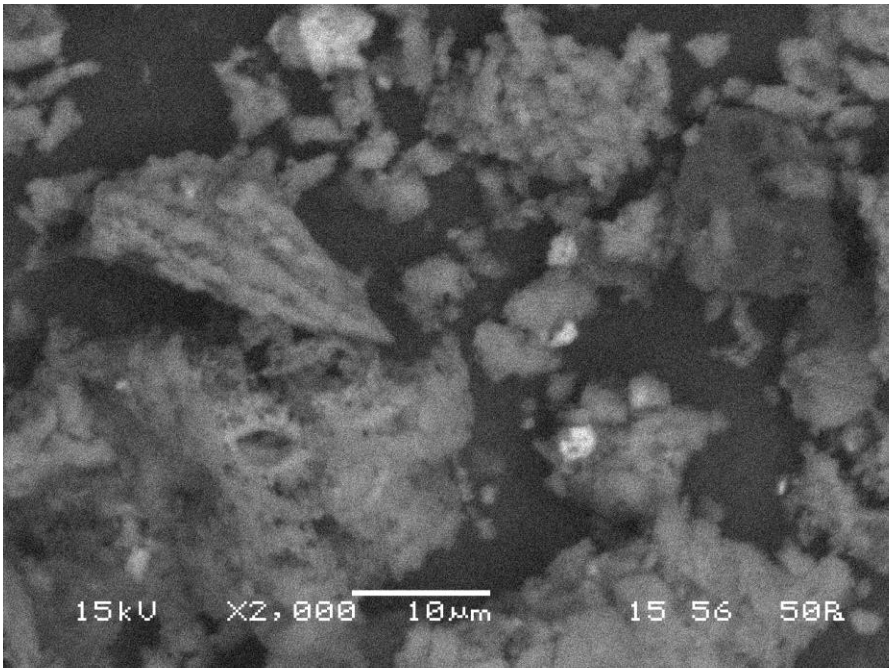

Photo3.4. Particle arrangement (SEM) at 2000M: Fly ash

The arrangement of particles in the BFS specimen is viewed at a magnification of 5000 and 2000 at 15 kV under the scanning electron microscope in a pressure of 50 Pa. The photograph of the magnified view is as follows:

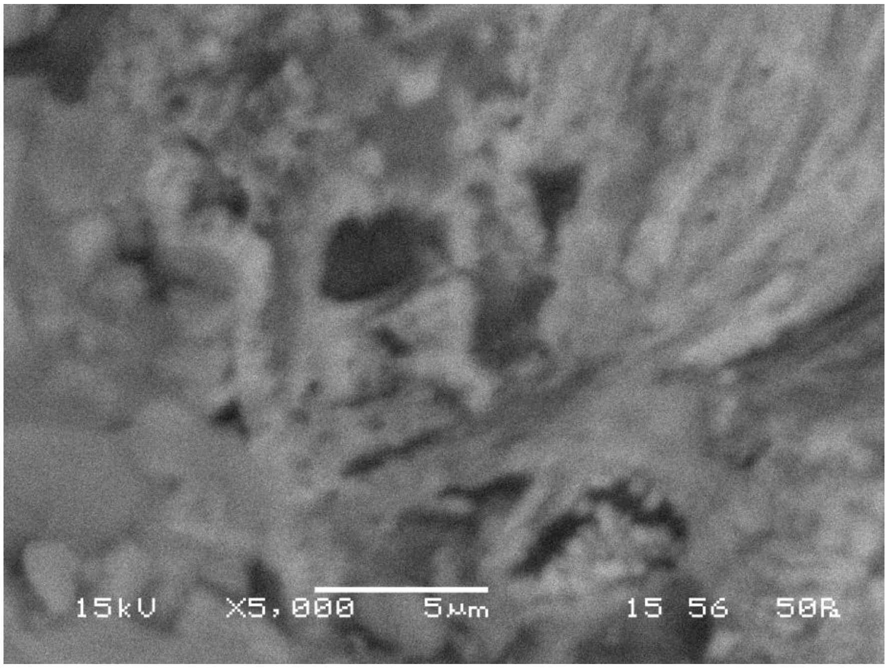

Photo3.5. Particle arrangement (SEM) at 5000M: BFS

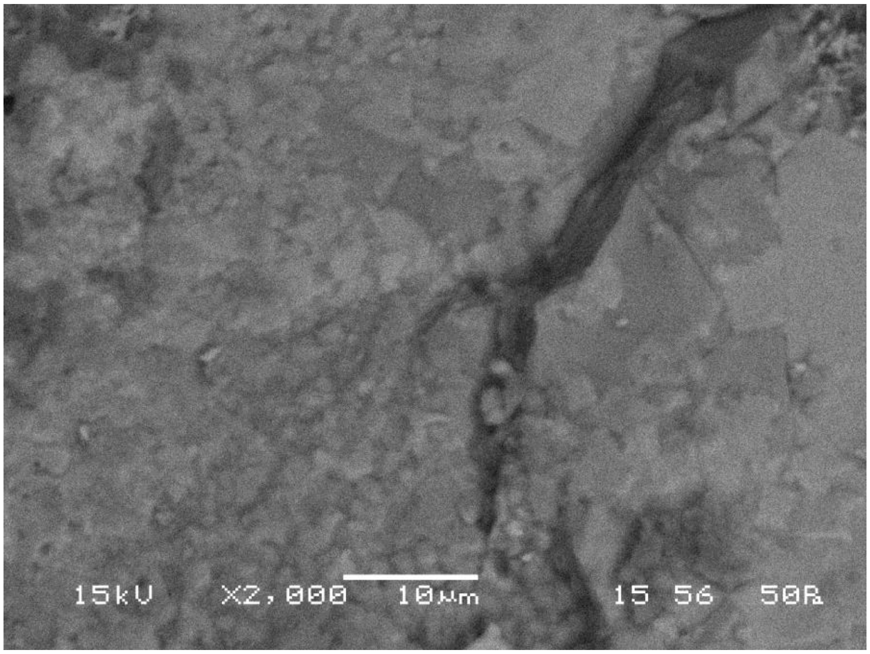

Photo3.6. Particle arrangement (SEM) at 2000M: BFS

The arrangement of particles in the Lime specimen is viewed at a magnification of 5000 and 2000 at 15 kV under the scanning electron microscope in a pressure of 50 Pa. The photograph of the magnified view is as follows:

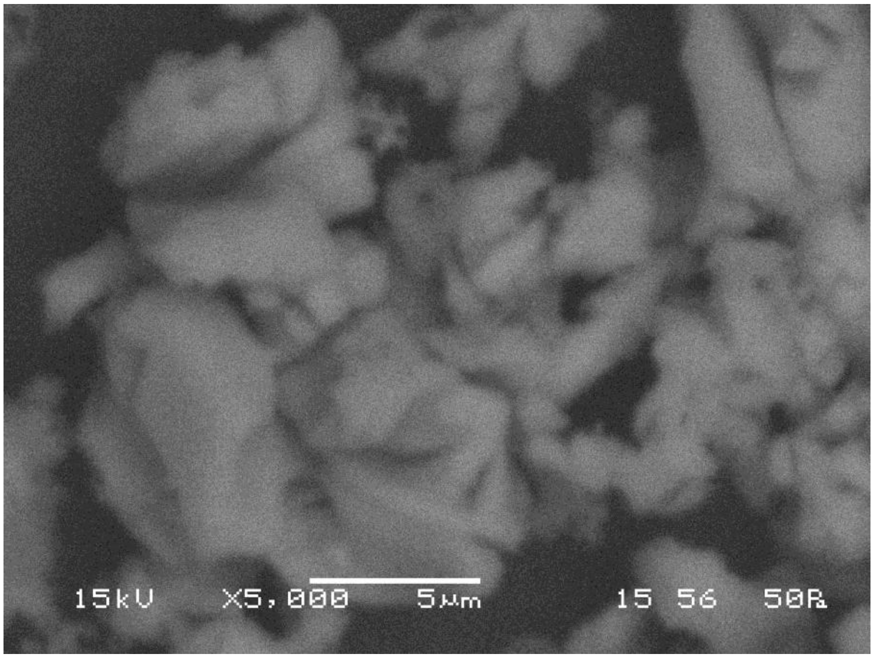

Photo3.7. Particle arrangement (SEM) at 5000M: Lime

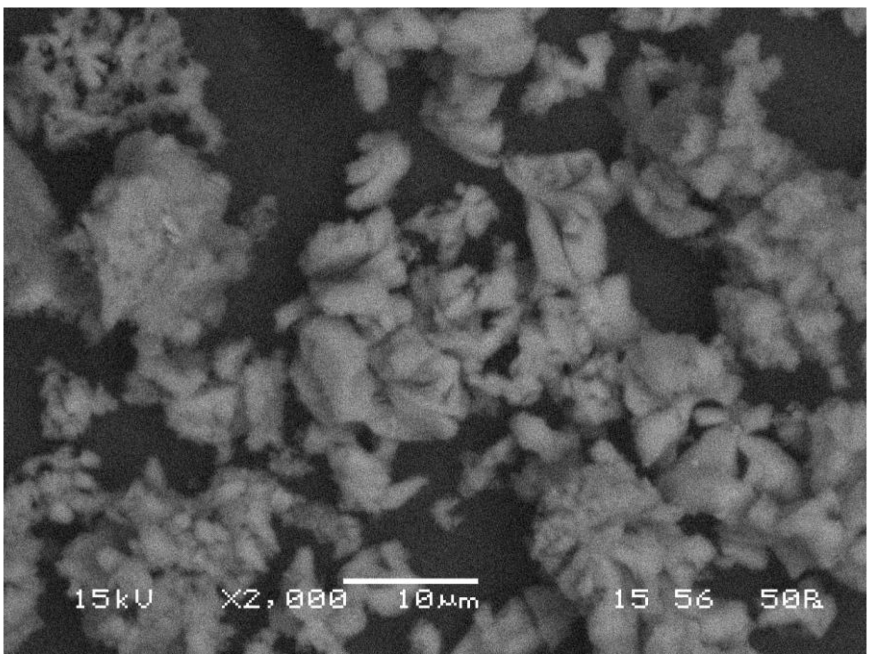

Photo3.8. Particle arrangement (SEM) at 2000M: Lime

The arrangement of particles in the RBI grade 81 specimen is viewed at a magnification of 5000 and 2000 at 15 kV under the scanning electron microscope in a pressure of 50 Pa. The photograph of the magnified view is as follows:

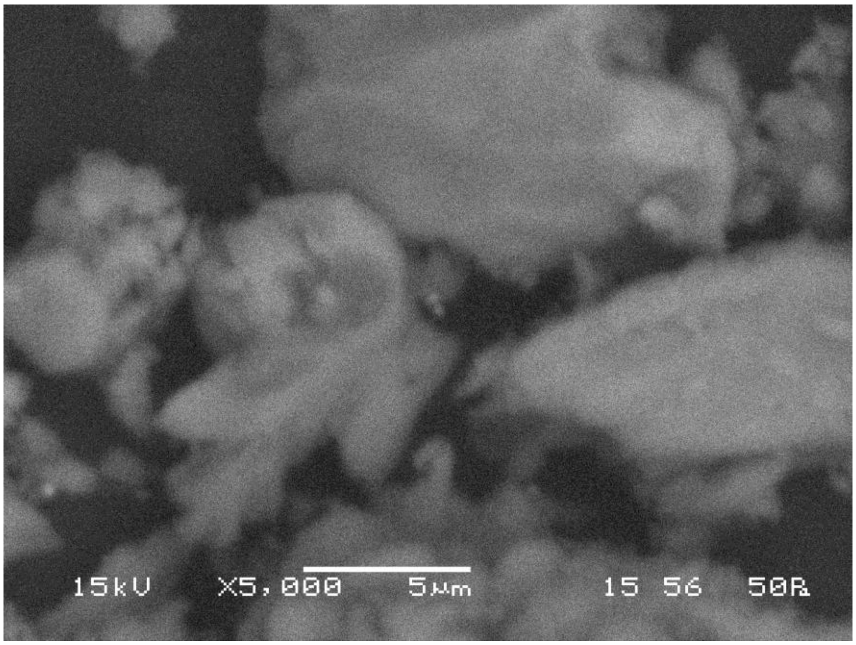

Photo3.9. Particle arrangement (SEM) at 5000M: RBI grade 81

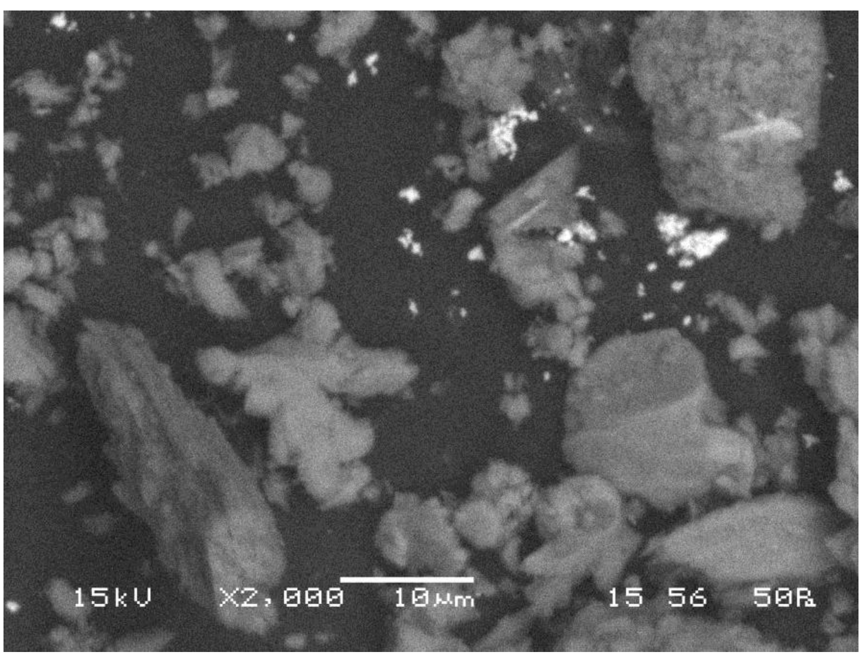

Photo3.10. Particle arrangement (SEM) at 2000M: RBI grade 81

3.5.2 MDD and OMC at different composition of BFS and fly ash

Table3.2. MDD and OMC at different compositions

SL .NO	% FLYASH	% BFS	MDD(gm/cm^3)	OMC (%)
1	100	0	1.08	40.1
2	90	10	1.164	36.1
3	80	20	1.251	31.7
4	70	30	1.31	30.3
5	60	40	1.39	24.8
6	50	50	1.52	23.7
7	40	60	1.69	20.5
8	30	70	1.86	17.2
9	20	80	2.012	13.7
10	10	90	2.1765	10.54

Table3.3. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and lime after 7 days of curing.

Fly ash percentage	BFS percentage	2% lime	4% lime	6% lime	8% lime
100	**0**	289.1	303.4	390.0	432.9
90	**10**	337.7	369.2	418.4	475.8
80	**20**	375.0	465.1	560.8	689.9
70	**30**	426.5	569.6	645.8	713.7
60	**40**	435.1	723.2	832.6	982.5
50	**50**	455.8	1299.0	1332.3	1382.2
40	**60**	516.6	1630.0	1731.9	1822.5
30	**70**	724.5	2141.3	2199.0	2345.0
20	**80**	912.5	2820.0	2855.0	2993.4
10	**90**	1019.0	2984.5	3033.0	3246.9

Table3.4. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and RBI Grade 81 after 7 days of curing.

Fly ash percentage	BFS percentage	2% RBI	4% RBI	6% RBI	8% RBI
100	**0**	203.9	265.5	286.0	424.83
90	**10**	231.9	287.9	322.8	462.2
80	**20**	254.9	296.2	356.8	472.4
70	**30**	267.8	318.0	407.8	486.0
60	**40**	287.9	323.0	424.8	492.8
50	**50**	311.3	403.7	518.3	628.7
40	**60**	329.7	426.8	730.7	781.7
30	**70**	390.8	567.4	1186.1	1988.2
20	**80**	535.6	644.4	2243.1	2472.5
10	**90**	732.7	1014.2	2447.0	2522.0

Table3.5. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and lime after 14 days of curing.

Fly ash percentage	BFS percentage	2% lime	4% lime	6% lime	8% lime
100	**0**	313.8	370.5	514.0	713.2
90	**10**	365.7	455.3	552.4	780.7
80	**20**	408.3	571.1	736.1	1132.5
70	**30**	462.4	699.4	852.1	1174.6
60	**40**	475.8	886.0	1097.3	1614.2
50	**50**	495.3	1595.1	1755.9	2269.9
40	**60**	565.5	2004.6	2280.6	2997.3
30	**70**	790.9	2626.5	2893.2	3851.8
20	**80**	998.7	3462.9	3760.8	4920.1
10	**90**	1109.6	3665.9	3991.4	5329.6

Table3.6. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and RBI Grade 81 after 14 days of curing.

Fly ash percentage	BFS percentage	2% RBI	4% RBI	6% RBI	8% RBI
100	**0**	208.6	297.0	345.6	603.2
90	**10**	232.5	324.1	391.2	655.0
80	**20**	253.3	331.4	432.4	667.5
70	**30**	267.1	356.8	494.2	686.7
60	**40**	286.1	361.4	513.8	694.3
50	**50**	310.4	451.7	628.1	887.3
40	**60**	328.7	477.5	885.6	1106.5
30	**70**	389.4	634.9	1438.5	2809.3
20	**80**	535.3	725.0	2718.6	3492.6
10	**90**	728.3	1134.8	2965.7	3567.5

Table3.7. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and lime after 28 days of curing.

Fly ash percentage	BFS percentage	2% lime	4% lime	6% lime	8% lime
100	**0**	322.2	398.0	579.9	819.4
90	**10**	376.5	482.3	624.1	905.6
80	**20**	418.2	610.2	833.9	1303.9
70	**30**	474.8	745.3	960.3	1354.0
60	**40**	485.4	947.8	1238.0	1861.8
50	**50**	507.5	1704.2	1985.1	2616.5
40	**60**	575.5	2139.5	2575.3	3449.9
30	**70**	810.9	2809.3	3264.9	4433.0
20	**80**	1024.1	3699.8	4241.3	5661.5
10	**90**	1139.2	3913.6	4510.0	6146.3

Table3.8. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and RBI Grade 81 after 28 days of curing.

Fly ash percentage	**BFS percentage**	**2% RBI**	**4% RBI**	**6% RBI**	**8% RBI**
100	**0**	225.9	317.0	376.3	645.3
90	**10**	253.7	343.7	427.8	702.0
80	**20**	283.1	352.6	469.5	718.5
70	**30**	297.3	379.6	535.6	734.2
60	**40**	315.5	385.6	559.0	749.5
50	**50**	344.3	482.0	685.0	954.9
40	**60**	369.6	514.5	961.6	1186.4
30	**70**	430.0	674.4	1560.9	3024.0
20	**80**	593.7	769.4	2953.9	3756.7
10	**90**	804.1	1210.9	3220.2	3832.9

Table3.9. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and lime after 60 days of curing.

Fly ash percentage	BFS percentage	2% lime	4% lime	6% lime	8% lime
100	**0**	366.0	436.2	654.0	970.9
90	**10**	427.5	530.9	701.6	1067.2
80	**20**	474.7	668.8	940.4	1547.4
70	**30**	539.9	819.0	1083.0	1600.8
60	**40**	550.8	1039.9	1396.2	2203.7
50	**50**	577.0	1867.9	2234.2	3100.2
40	**60**	654.0	2343.9	2904.3	4087.8
30	**70**	917.2	3079.1	3687.7	5259.8
20	**80**	1155.2	4055.1	4787.8	6714.1
10	**90**	1290.0	4291.7	5086.3	7282.7

Table3.10. Unconfined compressive strength (in KN/m^2) of samples of different composition of fly ash, slag and RBI Grade 81 after 60 days of curing.

Fly ash percentage	BFS percentage	2% RBI	4% RBI	6% RBI	8% RBI
100	**0**	226.1	327.6	405.9	715.2
90	**10**	259.3	356.2	458.3	774.0
80	**20**	282.9	365.5	506.7	793.1
70	**30**	298.3	392.4	581.2	816.9
60	**40**	322.7	398.5	605.4	827.4
50	**50**	346.7	495.1	738.5	1057.5
40	**60**	368.2	526.6	1038.7	1312.4
30	**70**	436.3	706.1	1686.8	3338.1
20	**80**	596.6	795.1	3190.9	4151.3
10	**90**	817.2	1252.5	3482.0	4235.4

CHAPTER 4

ANALYSIS OF RESULTS AND DISCUSSION

4.1 Grain size analysis: A particle size distribution curve gives us an idea about the type and the gradation of the soil. Grain size distribution indicates if a material is well graded, poorly graded, uniformly graded, fine or coarse.

4.1.1 Fly ash: The grain size analysis shows that it contains particles mostly of silt size with no plasticity. The percentage of clay and silt content is 89% and that of fine sand is 11%. The coefficient of uniformity (C_u) was found out to be 3.16 and the coefficient of curvature (C_c) was found out to be 1.04. The grain size analysis indicates fly ash is uniformly graded.

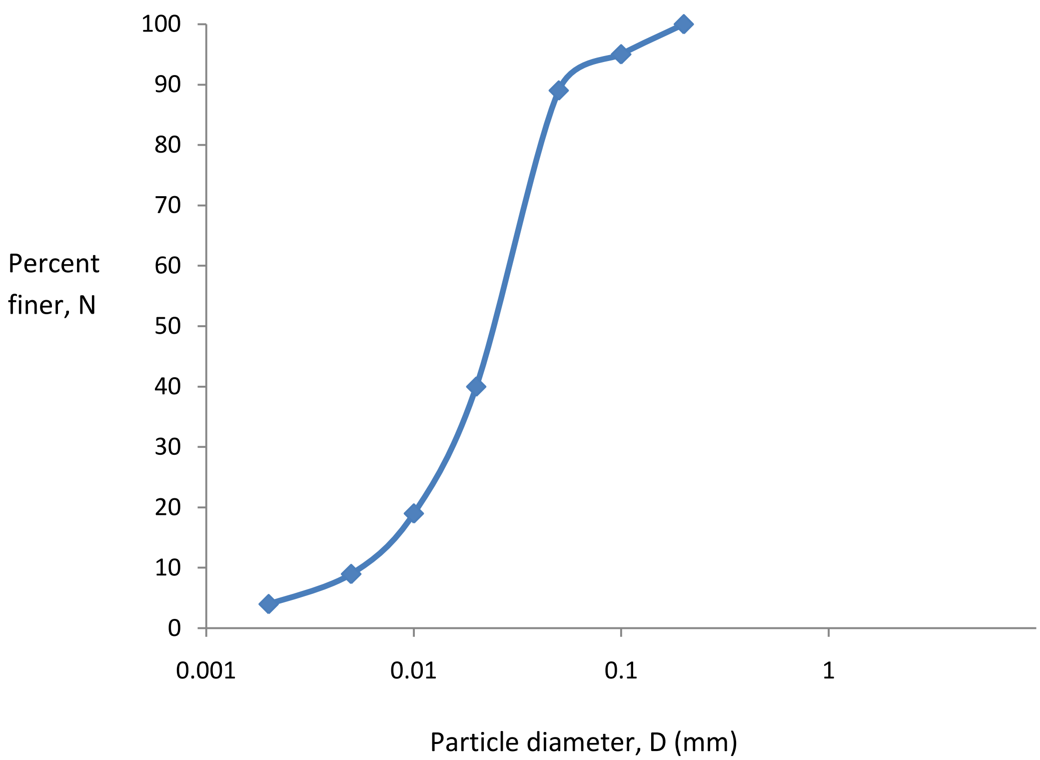

Fig4.2. Grain size distribution of Fly Ash

4.1.2 Blast furnace slag (BFS): The grain size analysis shows the percentage of clay and silt content is 0.023%, that of fine sand is 3.723%, medium sand is 13.013%, coarse sand is 17.96% and fine gravel is 63.45%. The coefficient of uniformity (C_u) was found out to be 5.9 and the coefficient of curvature (C_c) was found out to be 1.66. The grain size analysis indicates BFS is well graded.

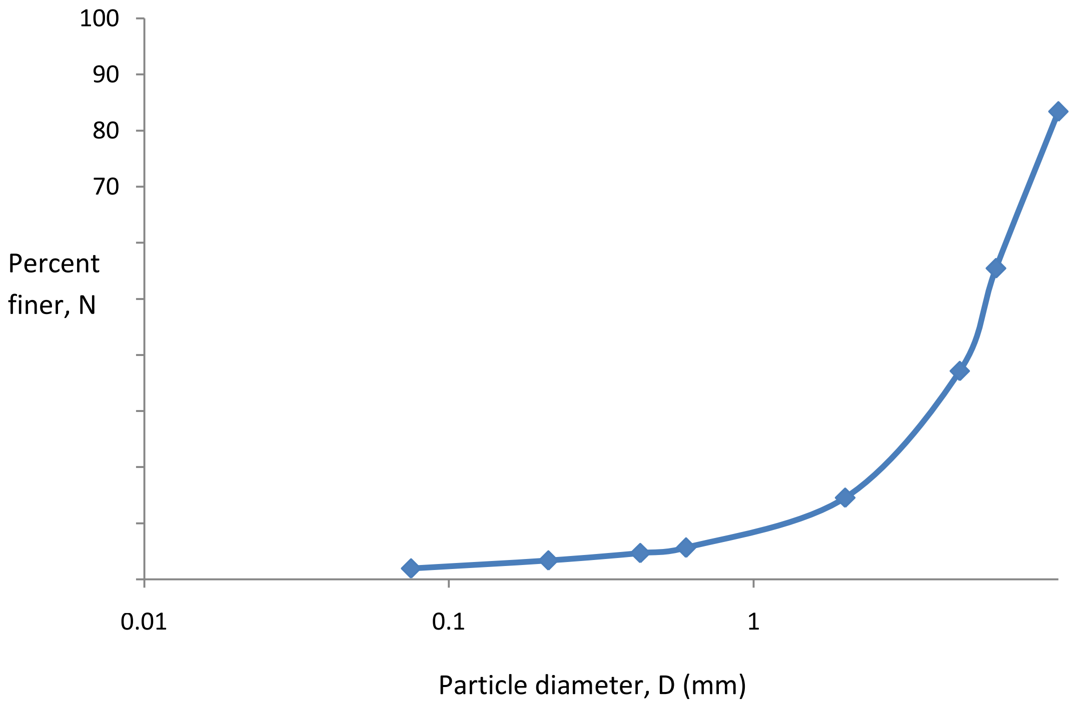

Fig4.2. Grain size distribution of Blast furnace slag (BFS)

4.2 Variation of OMC and MDD with BFS and fly ash content:

The following graphs are plotted to show the variation of OMC and MDD with BFS and fly ash content referring to the results shown in Table3.2.

4.2.1 Variation of OMC with fly ash content: With increase in fly ash content the optimum moisture content (OMC) increases linearly. It is in accordance with the general observation where optimum moisture content increases and maximum dry density decreases as the gradation of soil changes from coarse to fine. Fly ash is generally cenosphere which is light weight, inert and hollow sphere. With increase in fly ash content the hollow space increases hence the moisture content increases.

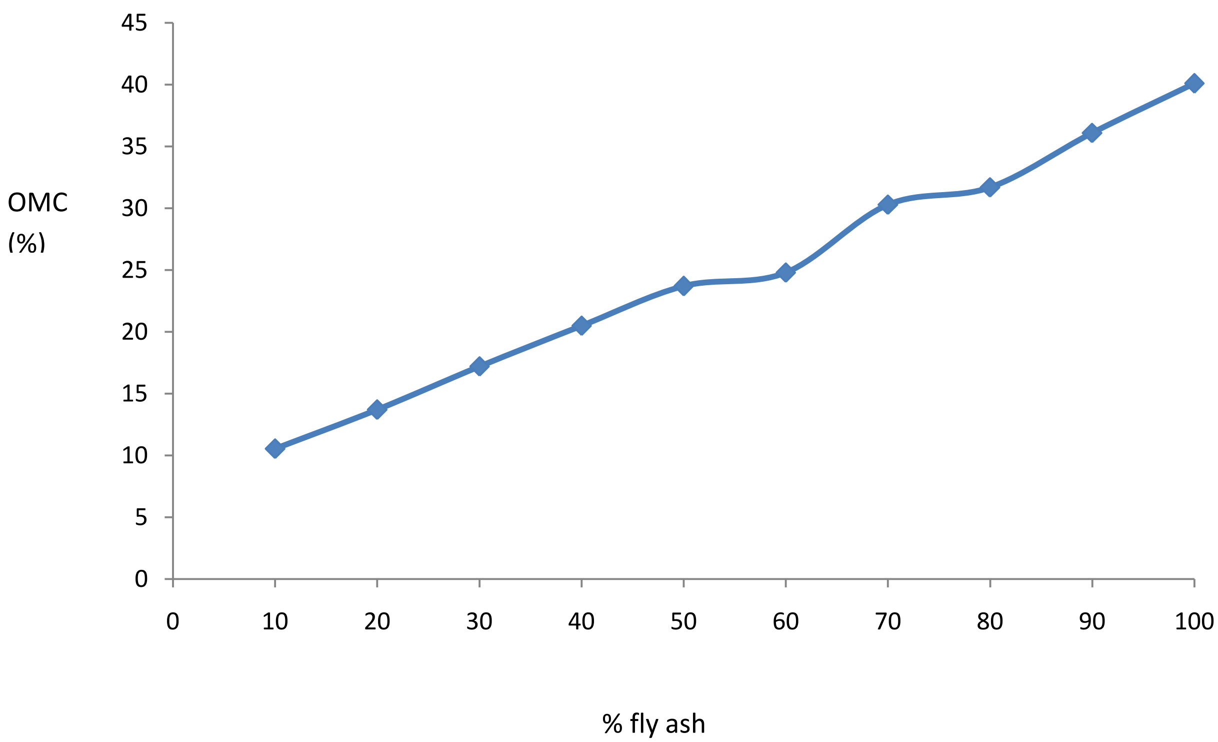

Fig4.3. Variation of OMC with fly ash content

4.2.2 Variation of MDD with fly ash content: It is observed that with the increase of fly ash the maximum dry density decreases linearly. It is due to the fact that fly ash has hollow structure and thus has low density. With increase in fly ash content thus the MDD decreases.

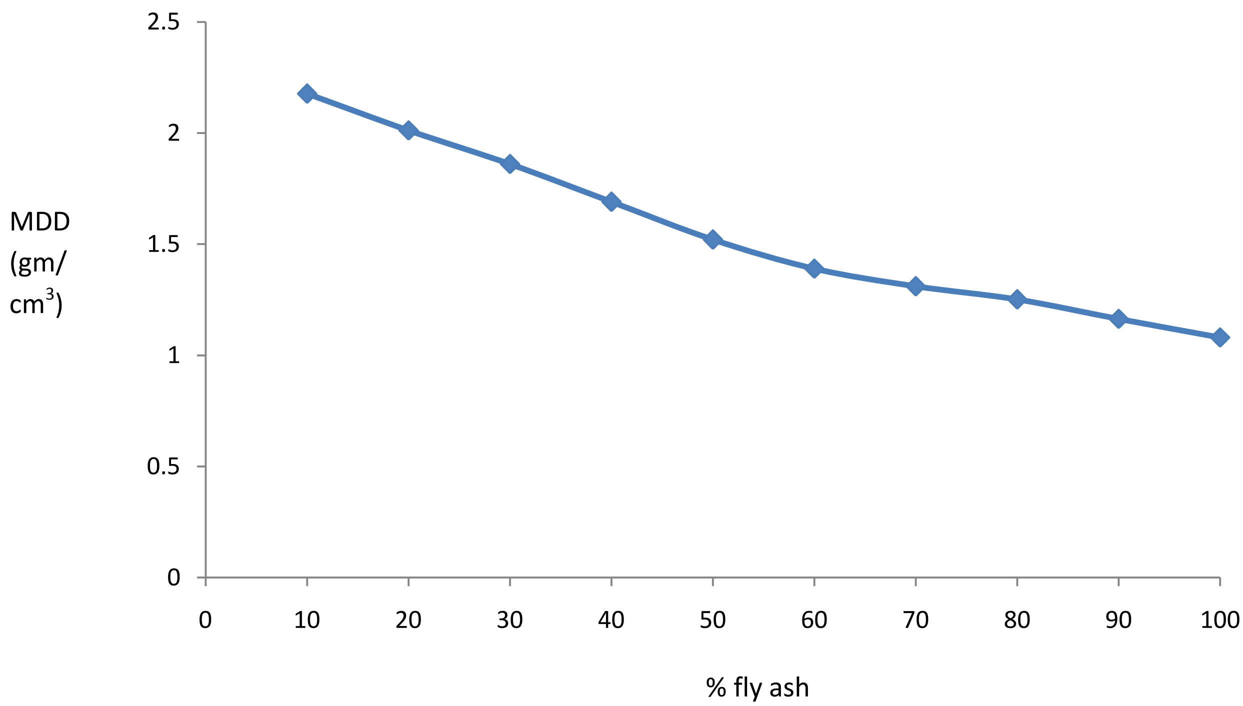

Fig4.4. Variation of MDD with fly ash content

4.2.3 Variation of OMC with BFS content: With increase in BFS content the optimum moisture content (OMC) linearly decreases. This is due to decrease in fly ash content.

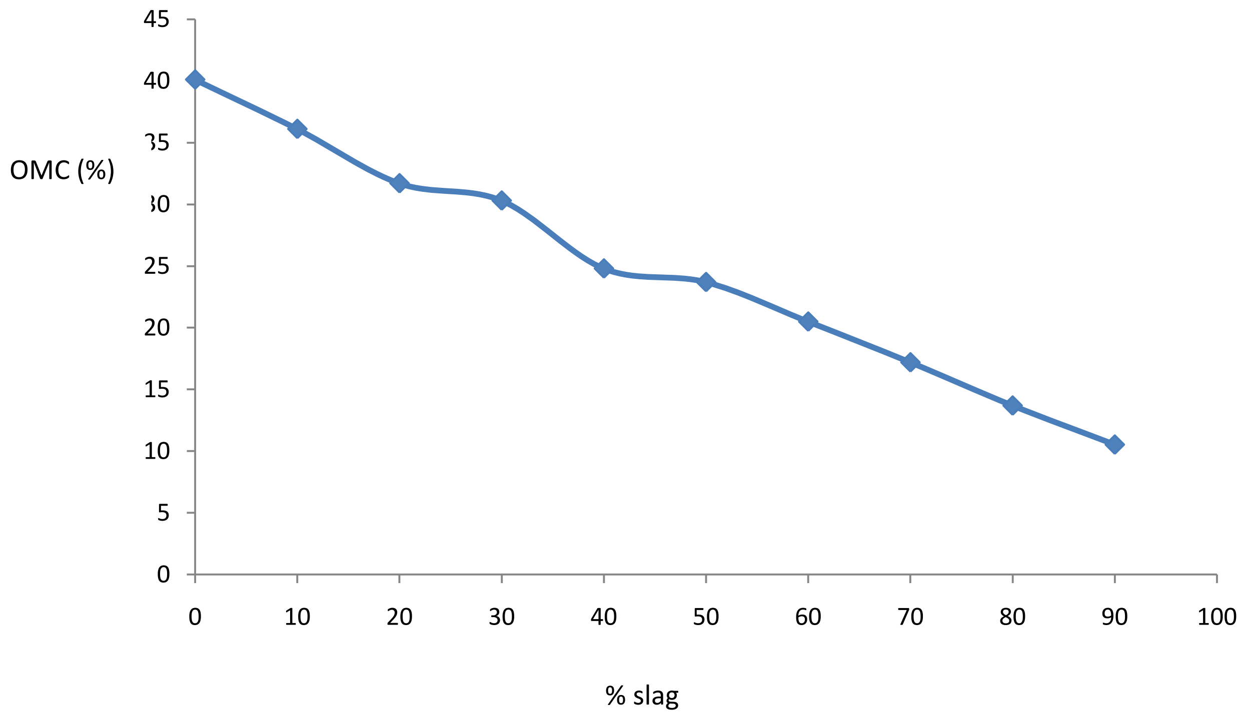

Fig4.5. Variation of OMC with BFS content

4.2.4 Variation of MDD with BFS content: With increase in BFS content the maximum dry density (MDD) gradually increases. This is due to the fact that the low density fly ash content decreases and the high density BFS increases thus MDD increases.

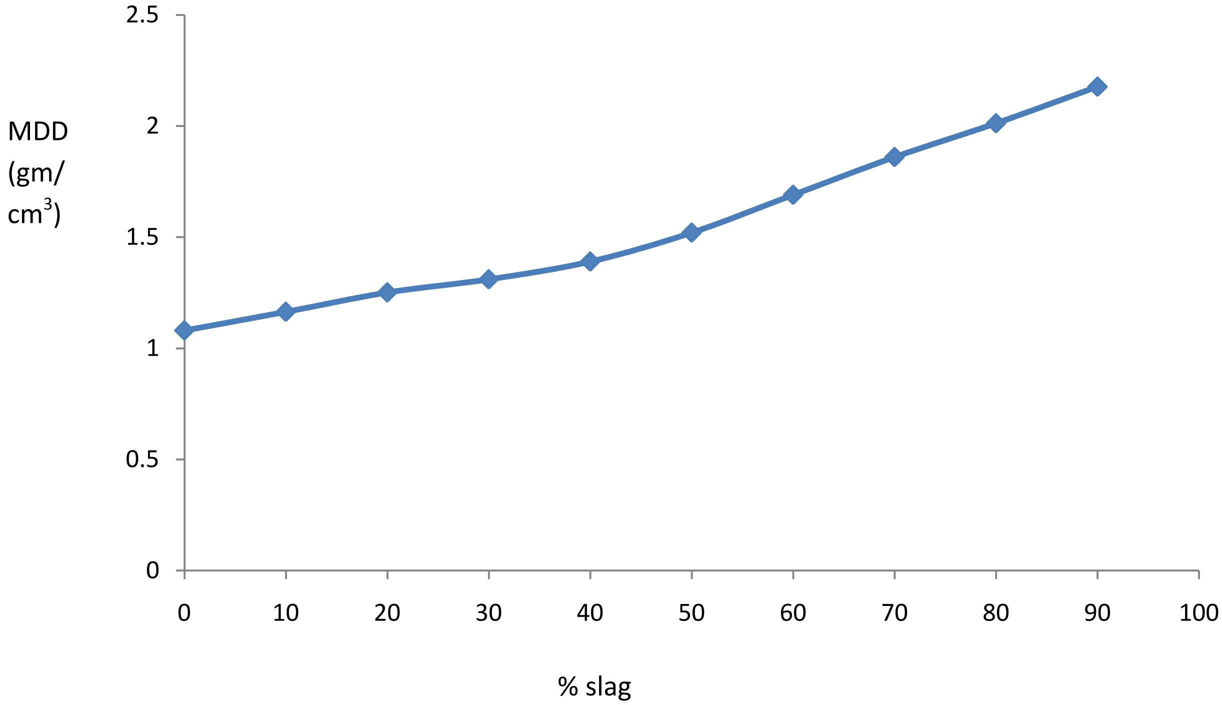

Fig4.6. Variation of MDD with BFS content

4.3. Variation of UCS value with BFS (%) and fly ash (%):

The following graphs are plotted between the fly ash (%) and the UCS value for different percentage of lime and RBI grade 81 for 7, 14, 28 and 60 days of curing referring to the experimental results shown in Table3.3, Table3.4, Table3.5, Table3.6, Table3.7, Table3.8, Table3.9 and Table3.10.

4.3.1 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 7 days curing:

The maximum UCS after 7 days curing was found out to be 3246.9 kN/m^2 for 10% fly ash + 90% BFS + 8% Lime.

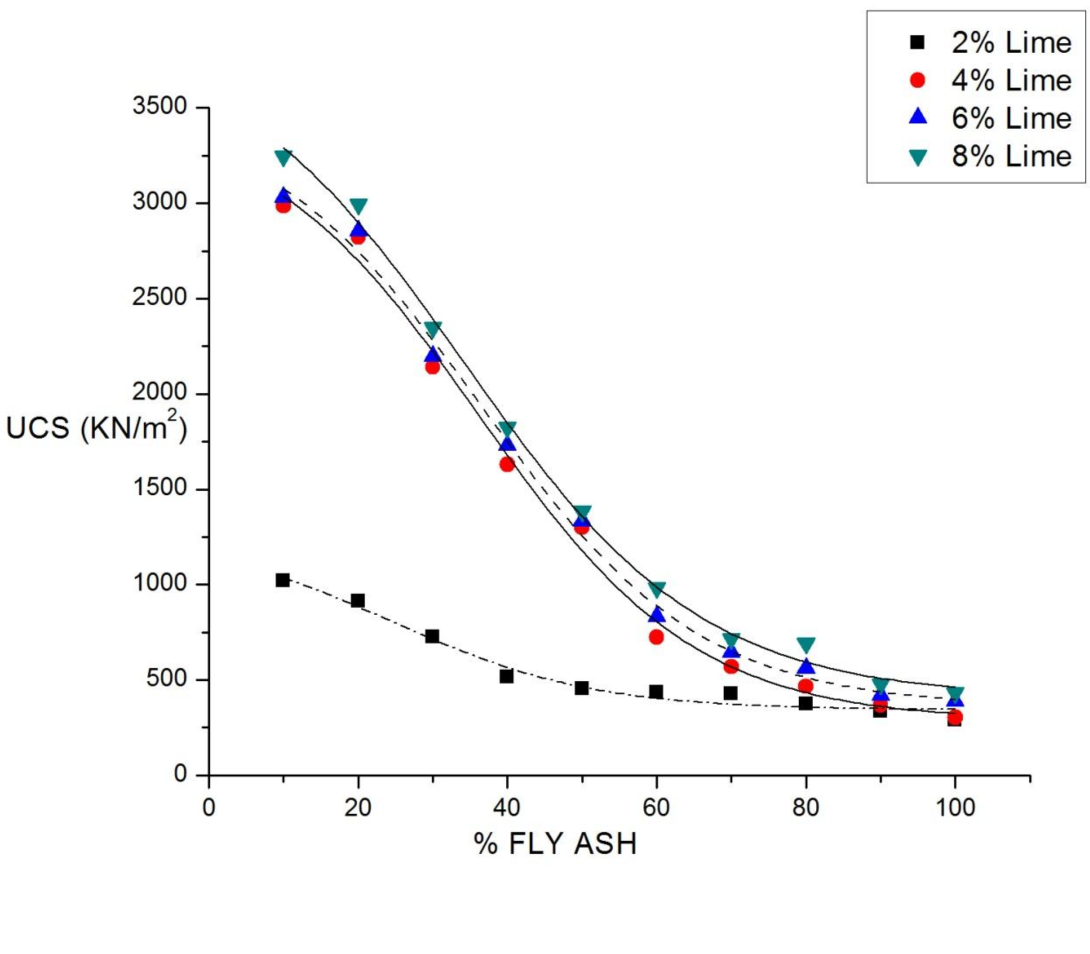

Fig4.7. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 7 days curing

4.3.2 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 7 days curing:

The maximum UCS after 7 days curing was found out to be 2522.0 kN/m^2 for 10% fly ash + 90% BFS + 8% RBI grade 81.

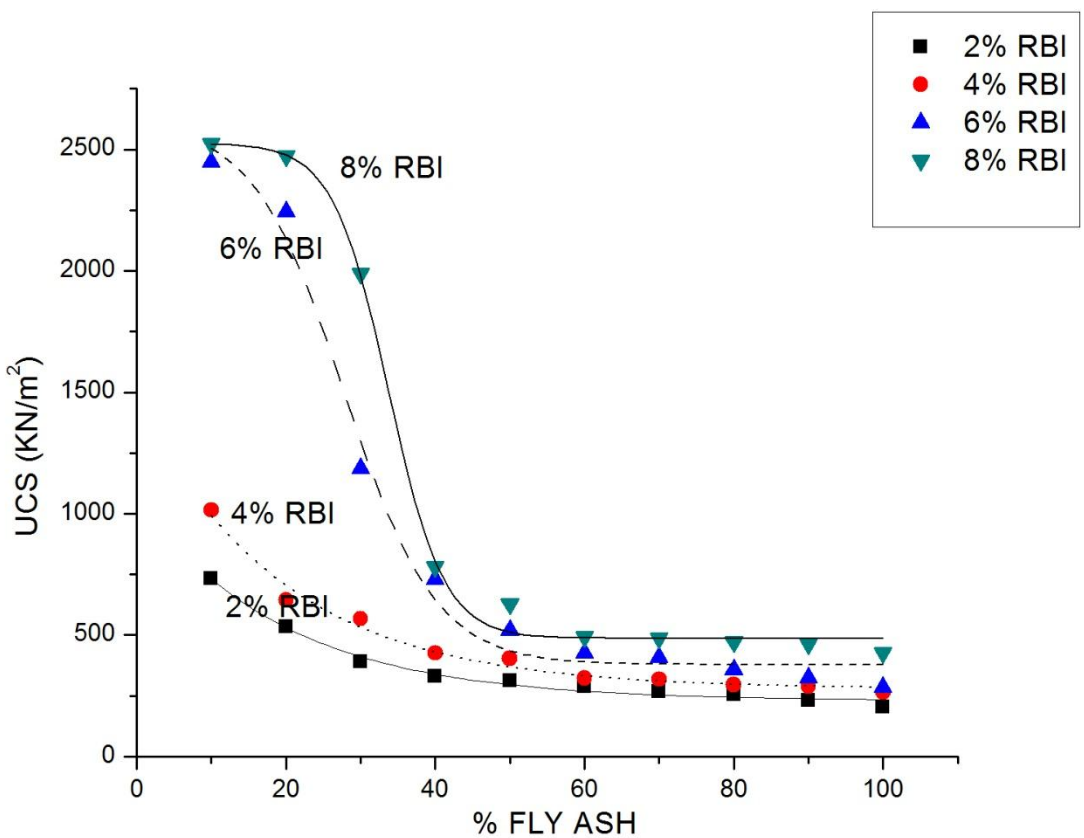

Fig4.8. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 7 days curing

4.3.3 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 14 days curing:

The maximum UCS after 14 days curing was found out to be 5329.6 kN/m^2 for 10% fly ash + 90% BFS + 8% Lime.

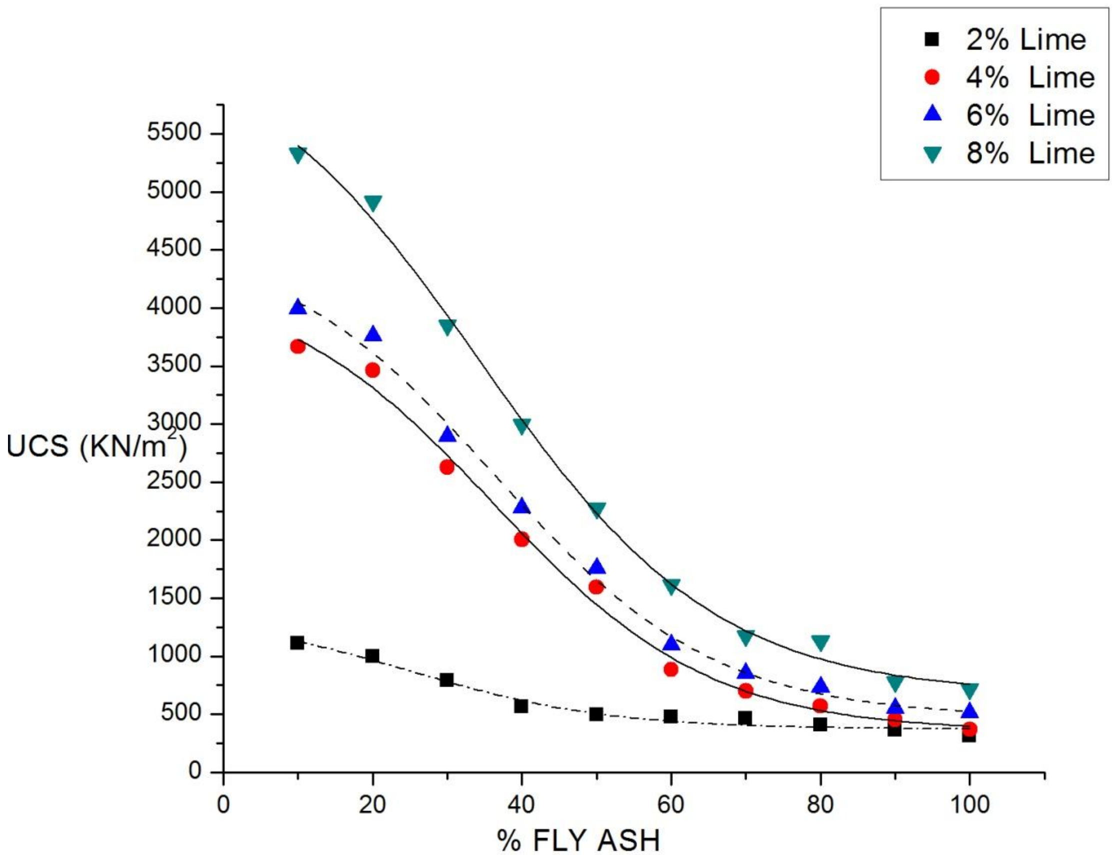

Fig4.9. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 14 days curing

4.3.4 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 14 days curing:

The maximum UCS after 14 days curing was found out to be 3567.5 kN/m^2 for 10% fly ash + 90% BFS + 8% RBI grade 81.

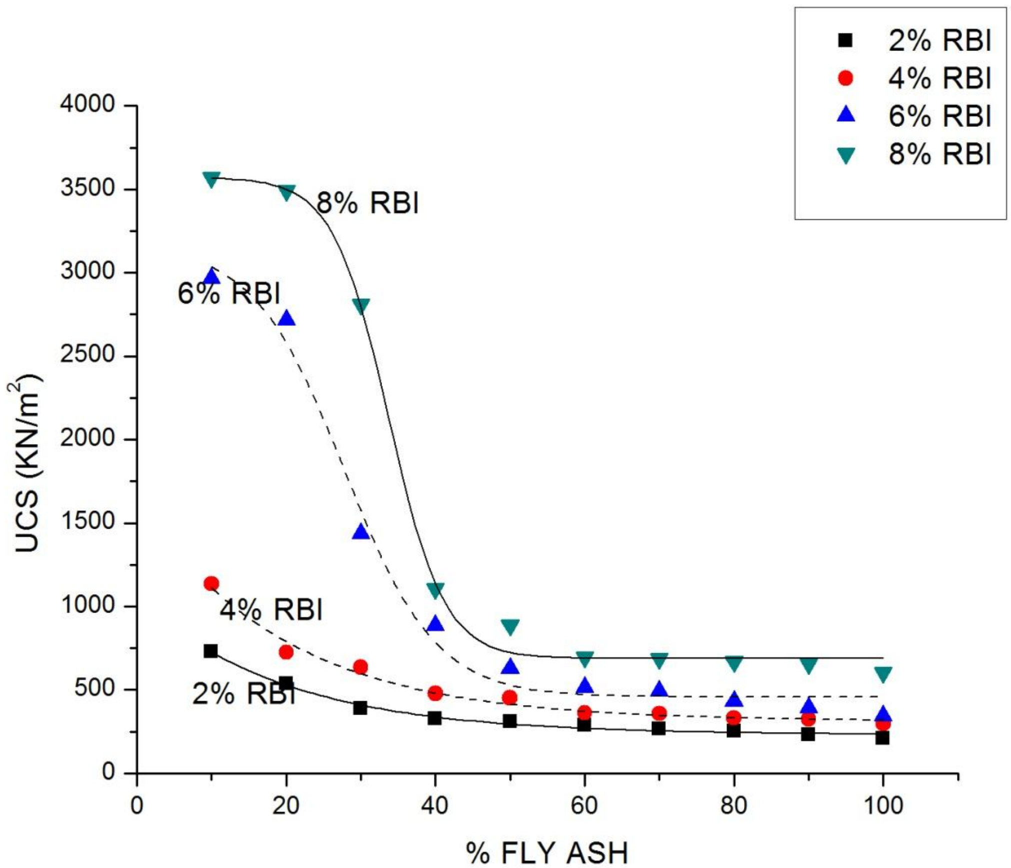

Fig4.10. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 14 days curing

4.3.5 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 28 days curing:

The maximum UCS after 28 days curing was found out to be 6146.3 kN/m^2 for 10% fly ash + 90% BFS + 8% Lime.

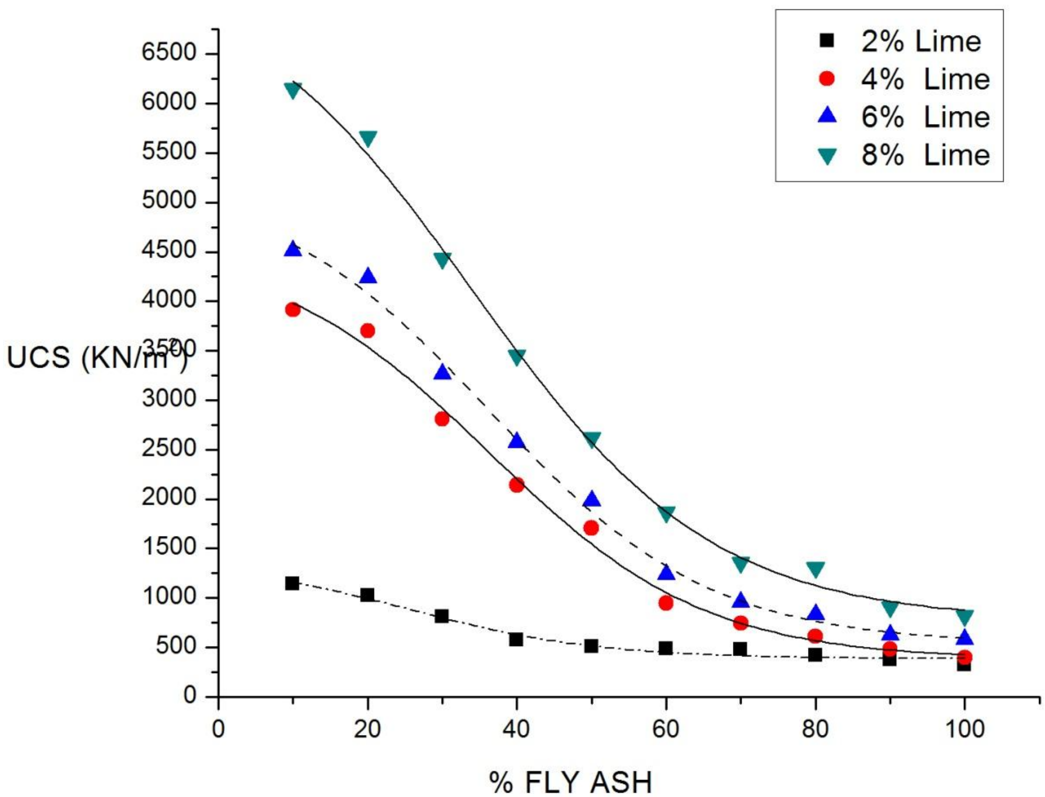

Fig4.11. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 28 days curing

4.3.6 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 28 days curing:

The maximum UCS after 28 days curing was found out to be 3832.9 kN/m^2 for 10% fly ash + 90% BFS + 8% RBI grade 81.

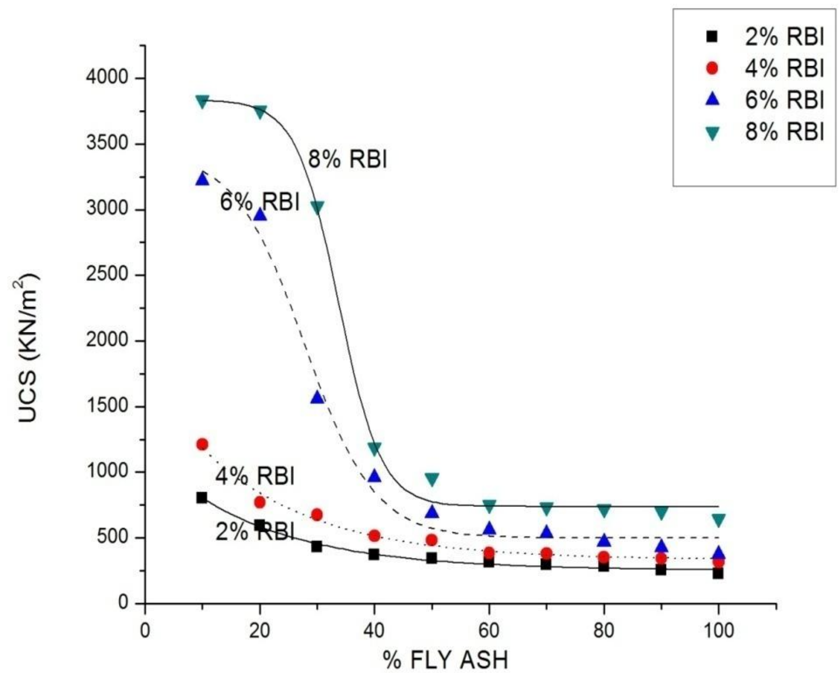

Fig4.12. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 28 days curing

4.3.7 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 60 days curing:

The maximum UCS after 60 days curing was found out to be 7282.7 kN/m^2 for 10% fly ash + 90% BFS + 8% Lime.

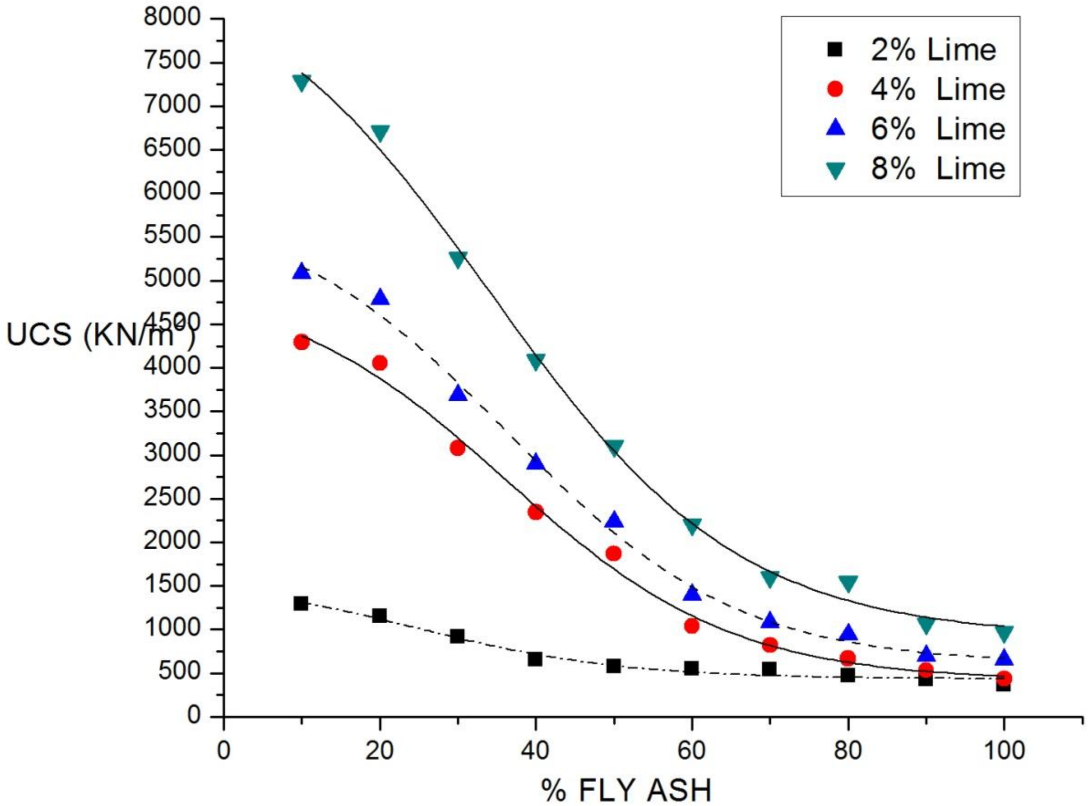

Fig4.13. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of lime for 60 days curing

4.3.8 Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 60 days curing:

The maximum UCS after 60 days curing was found out to be 4235.4 kN/m^2 for 10% fly ash + 90% BFS + 8% RBI grade 81.

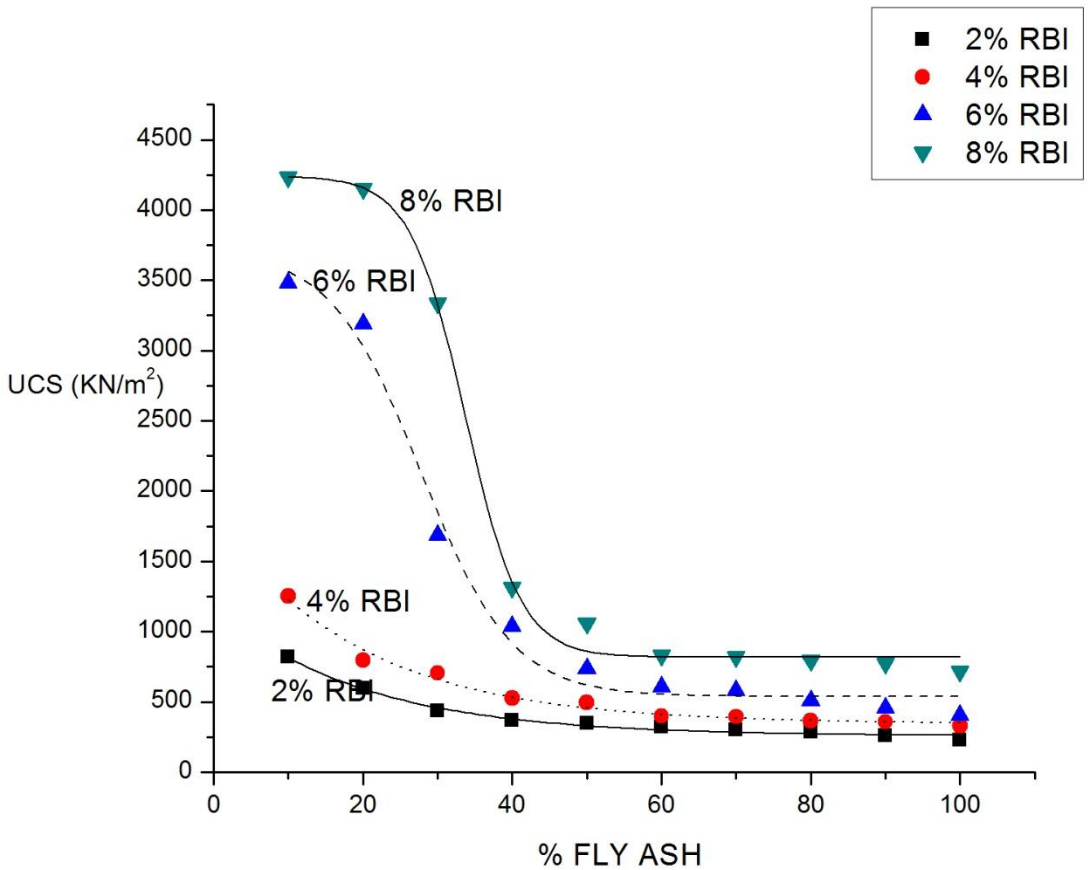

Fig4.14. Variation of UCS value with BFS (%) and fly ash (%) for different percentage of RBI grade 81 for 60 days curing

4.4 Variation of UCS value with curing period for BFS and fly ash mixes stabilized sample for different percentage of lime and RBI grade 81:

4.4.1 Variation of UCS value with curing period for 100% fly ash stabilized sample for different percentage of lime:

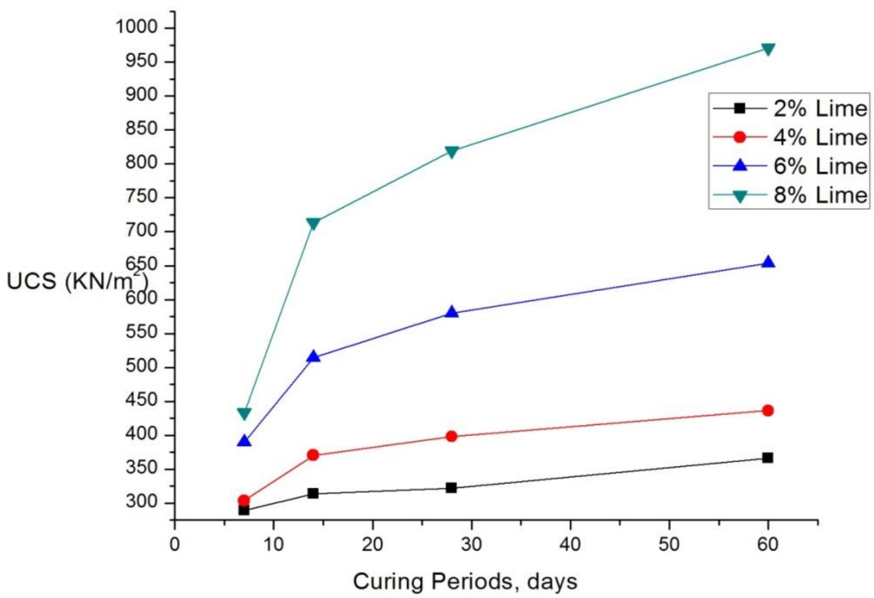

Fig4.15. Variation of UCS value with curing period for 100% fly ash stabilized sample for different percentage of lime

4.4.2 Variation of UCS value with curing period for 90% fly ash + 10% BFS stabilized sample for different percentage of lime:

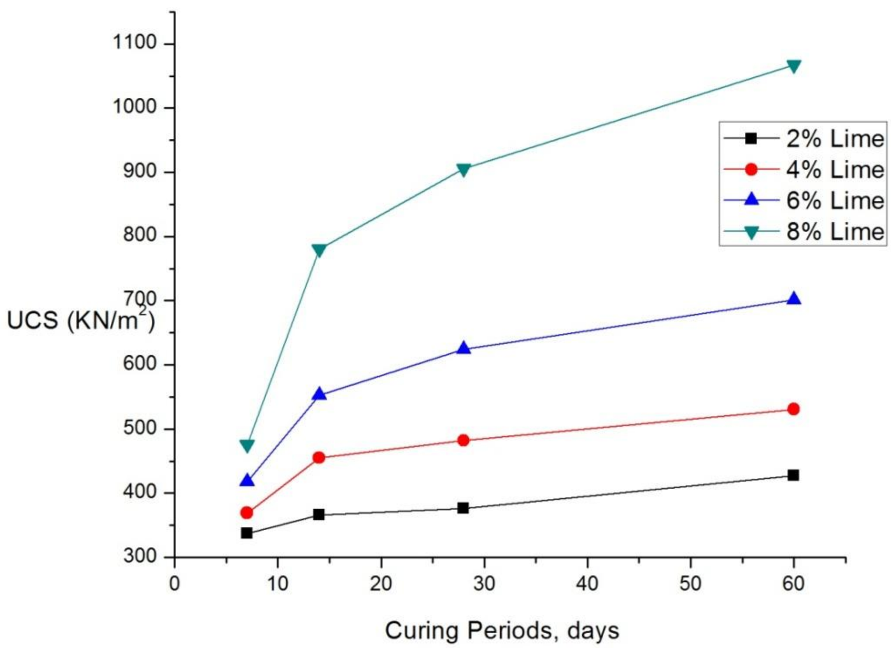

Fig4.16. Variation of UCS value with curing period for 90% fly ash + 10% BFS stabilized sample for different percentage of lime

4.4.3 Variation of UCS value with curing period for 80% fly ash + 20% BFS stabilized sample for different percentage of lime:

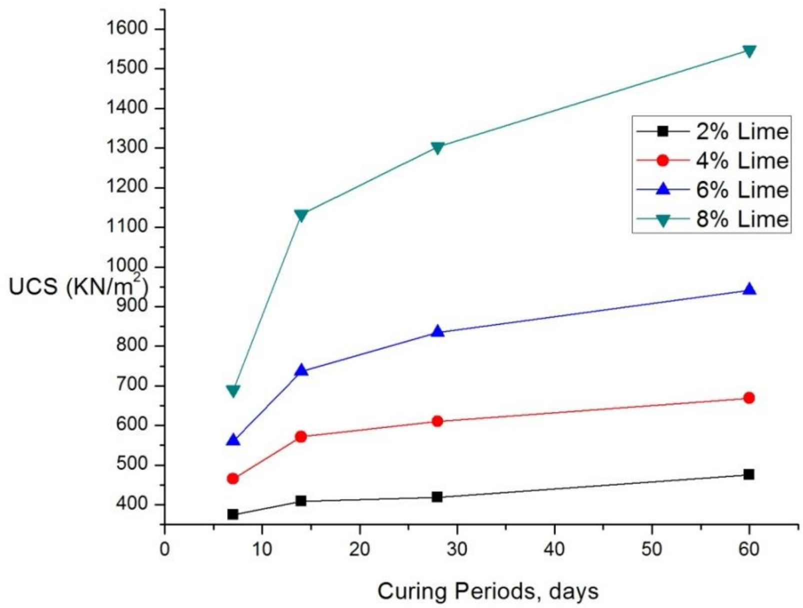

Fig4.17. Variation of UCS value with curing period for 80% fly ash + 20% BFS stabilized sample for different percentage of lime

4.4.4 Variation of UCS value with curing period for 70% fly ash + 30% BFS stabilized sample for different percentage of lime:

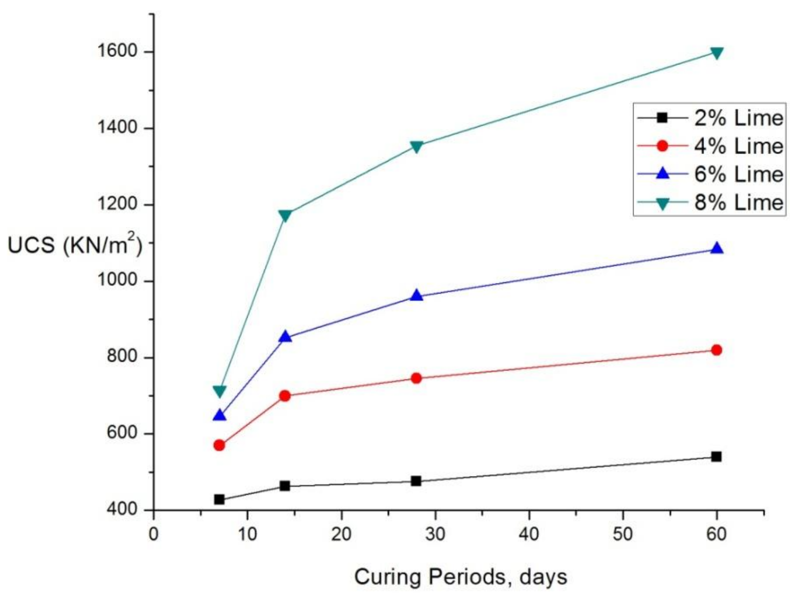

Fig4.18. Variation of UCS value with curing period for 70% fly ash + 30% BFS stabilized sample for different percentage of lime

4.4.5 Variation of UCS value with curing period for 60% fly ash + 40% BFS stabilized sample for different percentage of lime:

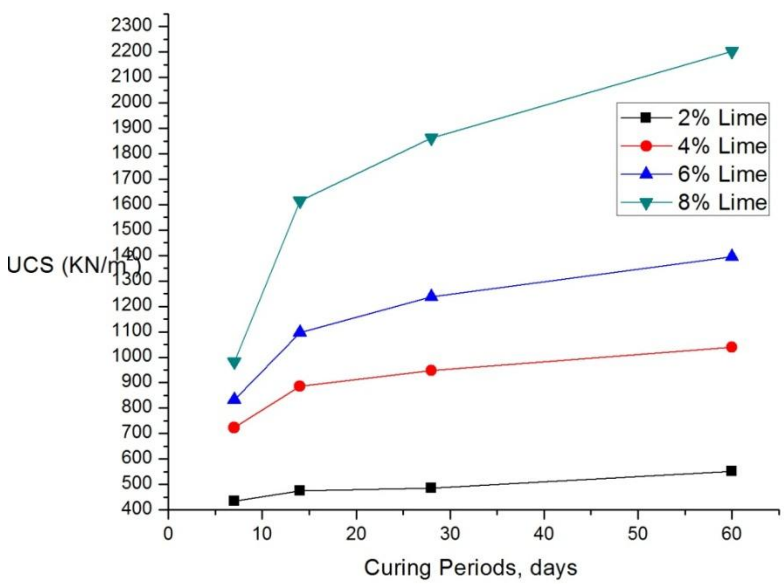

Fig4.19. Variation of UCS value with curing period for 60% fly ash + 40% BFS stabilized sample for different percentage of lime

4.4.6 Variation of UCS value with curing period for 50% fly ash + 50% BFS stabilized sample for different percentage of lime:

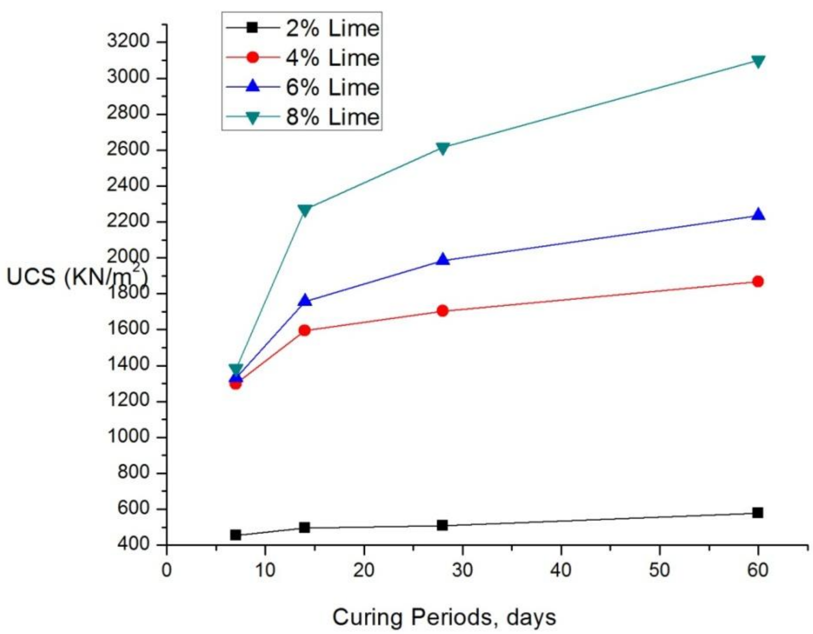

Fig4.20. Variation of UCS value with curing period for 50% fly ash + 50% BFS stabilized sample for different percentage of lime

4.4.7 Variation of UCS value with curing period for 40% fly ash + 60% BFS stabilized sample for different percentage of lime:

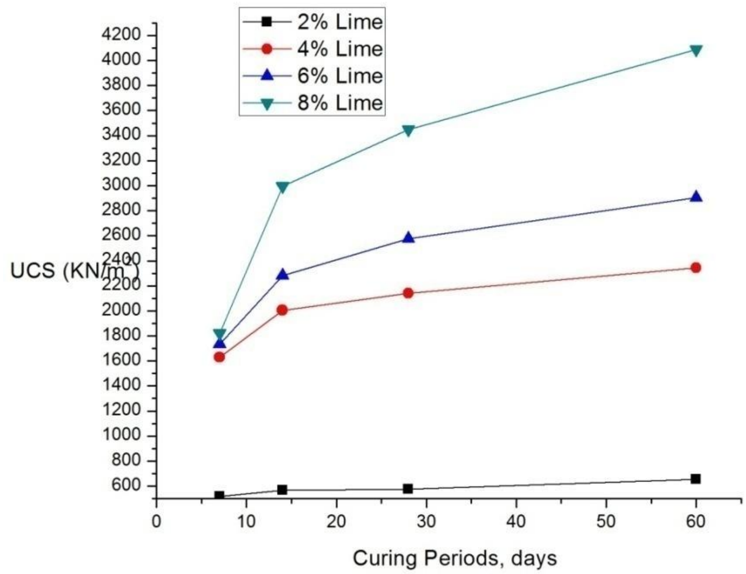

Fig4.21. Variation of UCS value with curing period for 40% fly ash + 60% BFS stabilized sample for different percentage of lime

4.4.8 Variation of UCS value with curing period for 30% fly ash + 70% BFS stabilized sample for different percentage of lime:

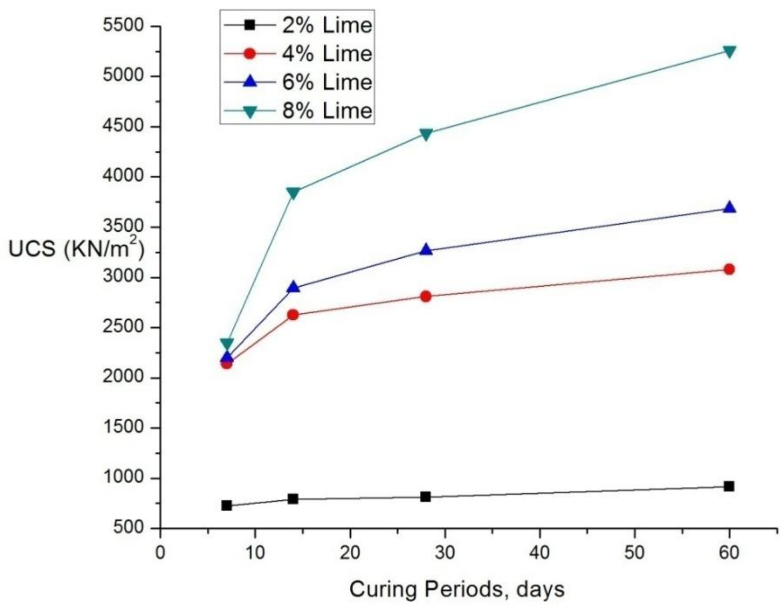

Fig4.22. Variation of UCS value with curing period for 30% fly ash + 70% BFS stabilized sample for different percentage of lime

4.4.9 Variation of UCS value with curing period for 20% fly ash + 80% BFS stabilized sample for different percentage of lime:

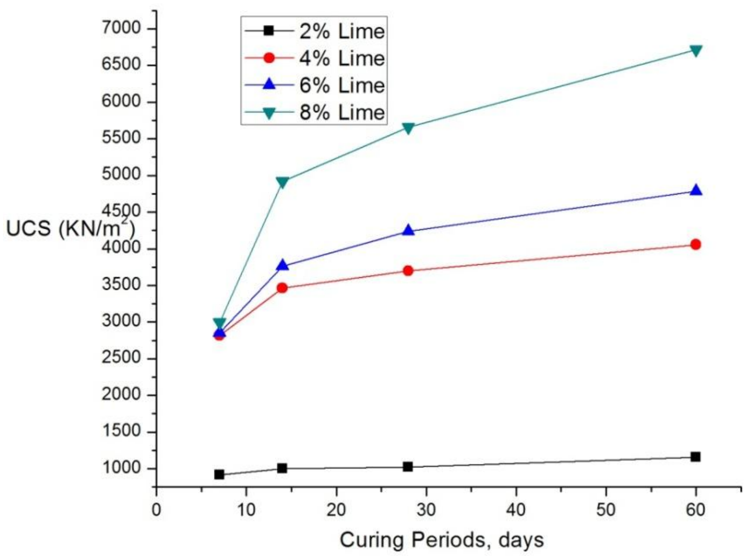

Fig4.23. Variation of UCS value with curing period for 20% fly ash + 80% BFS stabilized sample for different percentage of lime

4.4.10 Variation of UCS value with curing period for 10% fly ash + 90% BFS stabilized sample for different percentage of lime:

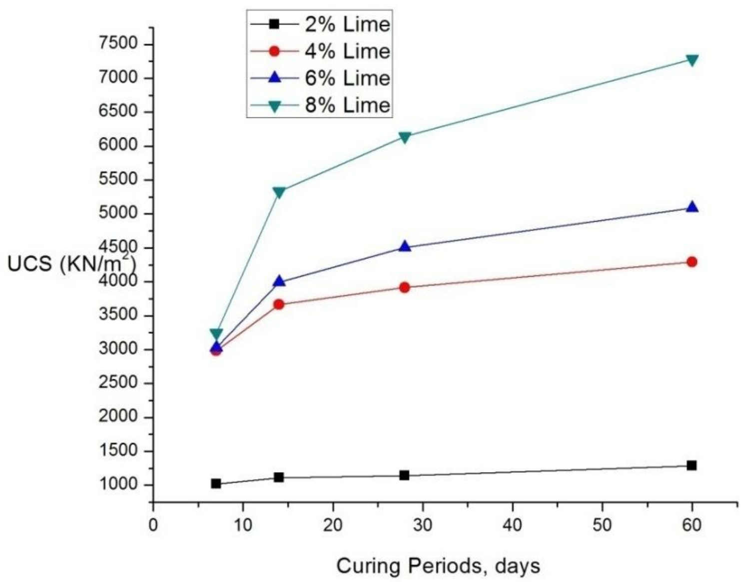

Fig4.24. Variation of UCS value with curing period for 10% fly ash + 90% BFS stabilized sample for different percentage of lime

4.4.11 Variation of UCS value with curing period for 100% fly ash stabilized sample for different percentage of RBI grade 81:

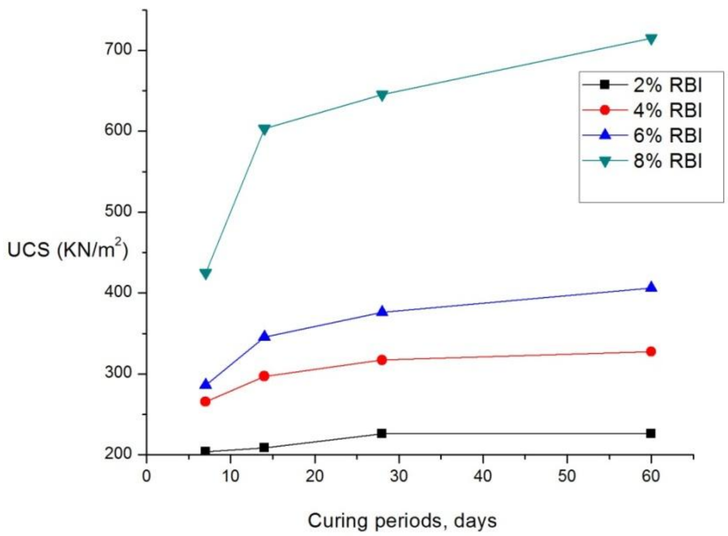

Fig4.25. Variation of UCS value with curing period for 100% fly ash stabilized sample for different percentage of RBI grade 81

4.4.12 Variation of UCS value with curing period for 90% fly ash + 10% BFS stabilized sample for different percentage of RBI grade 81:

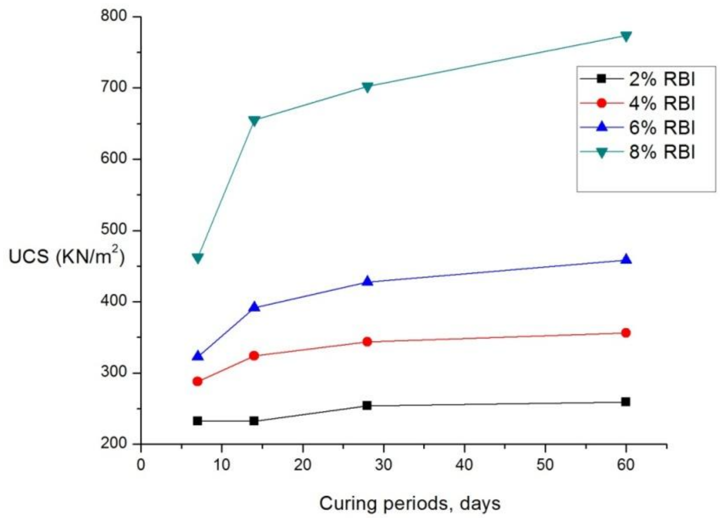

Fig4.26. Variation of UCS value with curing period for 90% fly ash + 10% BFS stabilized sample for different percentage of RBI grade 81

4.4.13 Variation of UCS value with curing period for 80% fly ash + 20% BFS stabilized sample for different percentage of RBI grade 81:

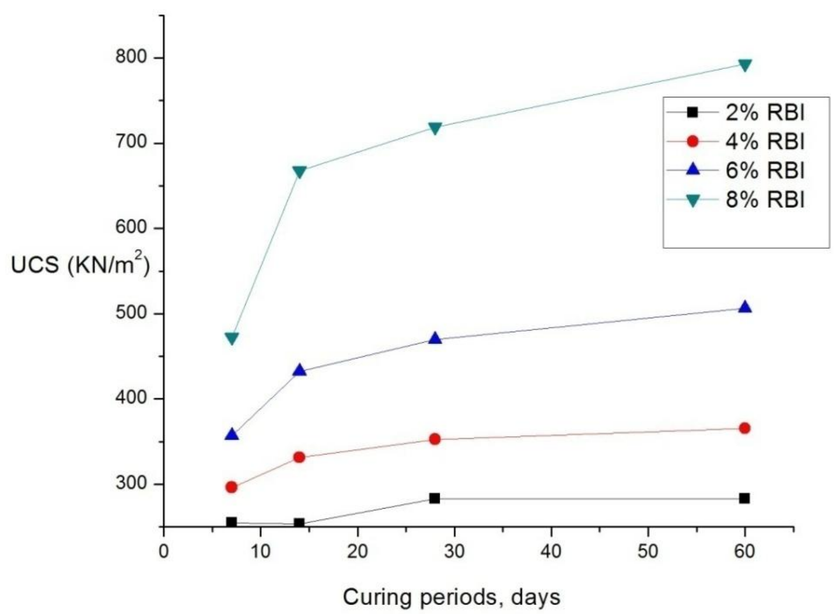

Fig4.27. Variation of UCS value with curing period for 80% fly ash + 20% BFS stabilized sample for different percentage of RBI grade 81

4.4.14 Variation of UCS value with curing period for 70% fly ash + 30% BFS stabilized sample for different percentage of RBI grade 81:

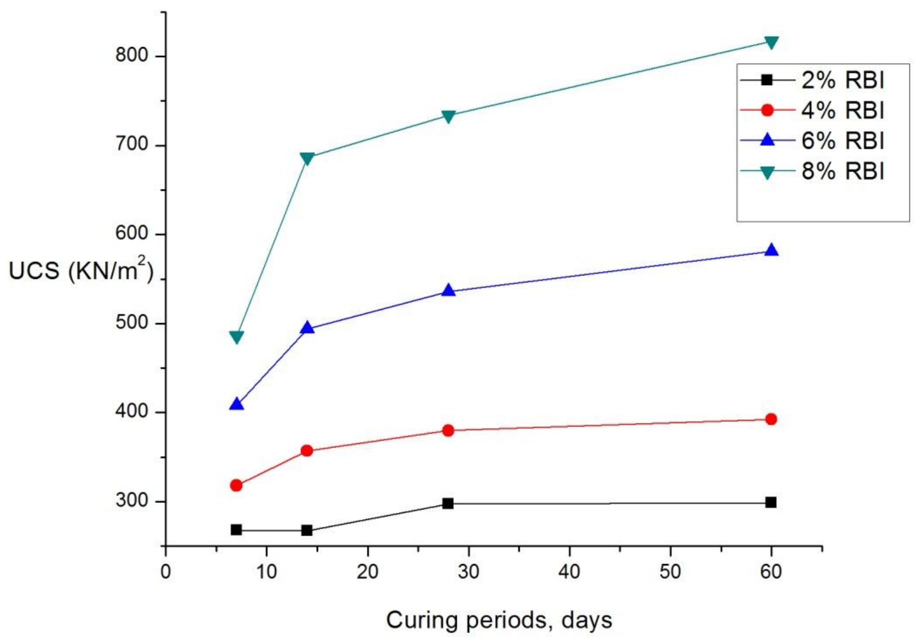

Fig4.28. Variation of UCS value with curing period for 70% fly ash + 30% BFS stabilized sample for different percentage of RBI grade 81

4.4.15 Variation of UCS value with curing period for 60% fly ash + 40% BFS stabilized sample for different percentage of RBI grade 81:

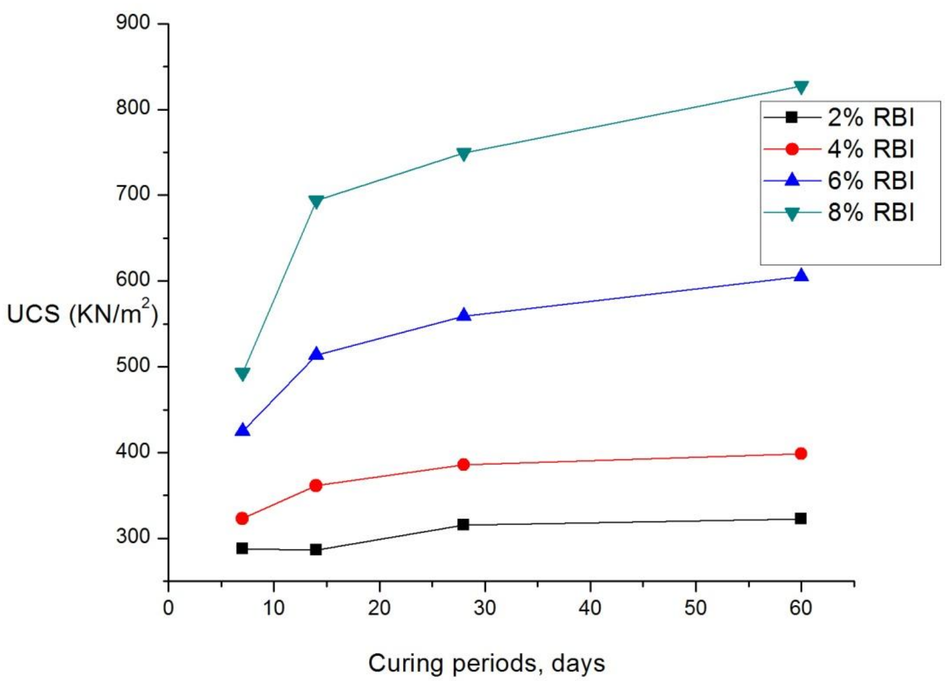

Fig4.29. Variation of UCS value with curing period for 60% fly ash + 40% BFS stabilized sample for different percentage of RBI grade 81

4.4.16 Variation of UCS value with curing period for 50% fly ash + 50% BFS stabilized sample for different percentage of RBI grade 81:

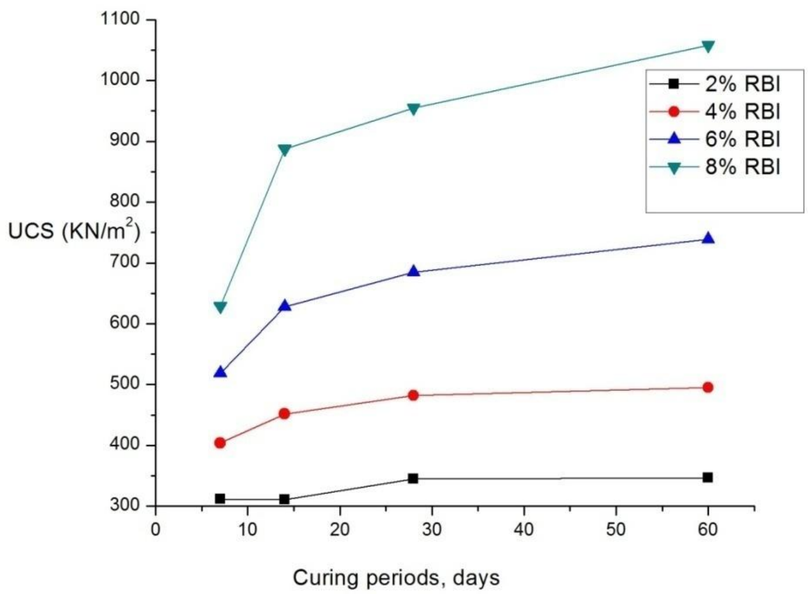

Fig4.30. Variation of UCS value with curing period for 50% fly ash + 50% BFS stabilized sample for different percentage of RBI grade 81

4.4.17 Variation of UCS value with curing period for 40% fly ash + 60% BFS stabilized sample for different percentage of RBI grade 81:

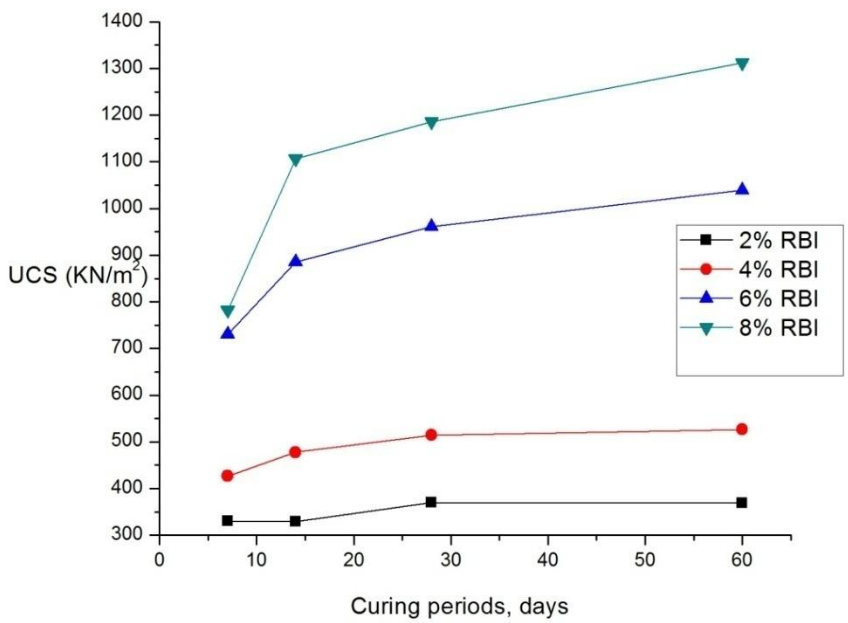

Fig4.31. Variation of UCS value with curing period for 40% fly ash + 60% BFS stabilized sample for different percentage of RBI grade 81

4.4.18 Variation of UCS value with curing period for 30% fly ash + 70% BFS stabilized sample for different percentage of RBI grade 81:

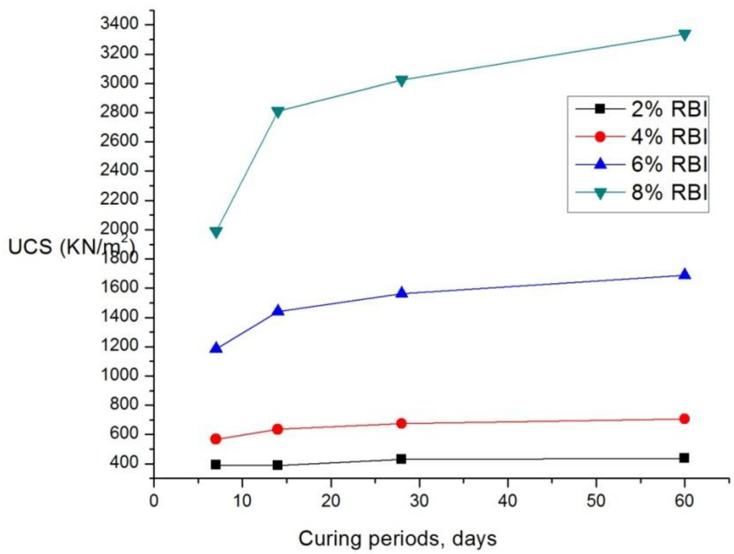

Fig4.32. Variation of UCS value with curing period for 30% fly ash + 70% BFS stabilized sample for different percentage of RBI grade 81

4.4.19 Variation of UCS value with curing period for 20% fly ash + 80% BFS stabilized sample for different percentage of RBI grade 81:

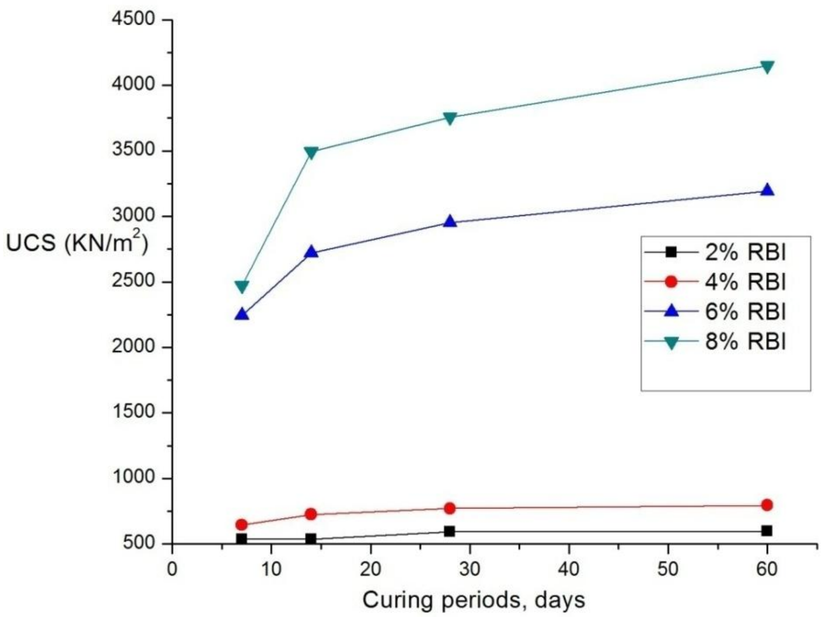

Fig4.33. Variation of UCS value with curing period for 20% fly ash + 80% BFS stabilized sample for different percentage of RBI grade 81

4.4.20 Variation of UCS value with curing period for 10% fly ash + 90% BFS stabilized sample for different percentage of RBI grade 81:

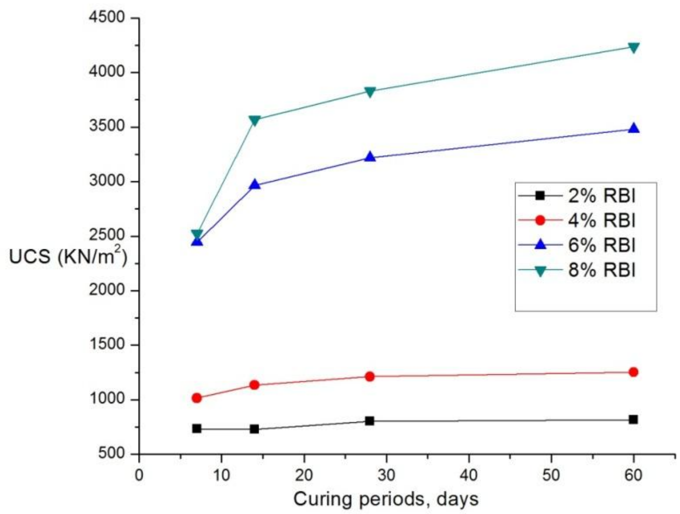

Fig4.34. Variation of UCS value with curing period for 10% fly ash + 90% BFS stabilized sample for different percentage of RBI grade 81

4.5. Comparison of UCS value for RBI and Lime at 2% and 6% and at 4% and 8% for different composition of BFS and fly ash for 7, 14, 28 and 60 days curing:

4.5.1 Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 7 days curing:

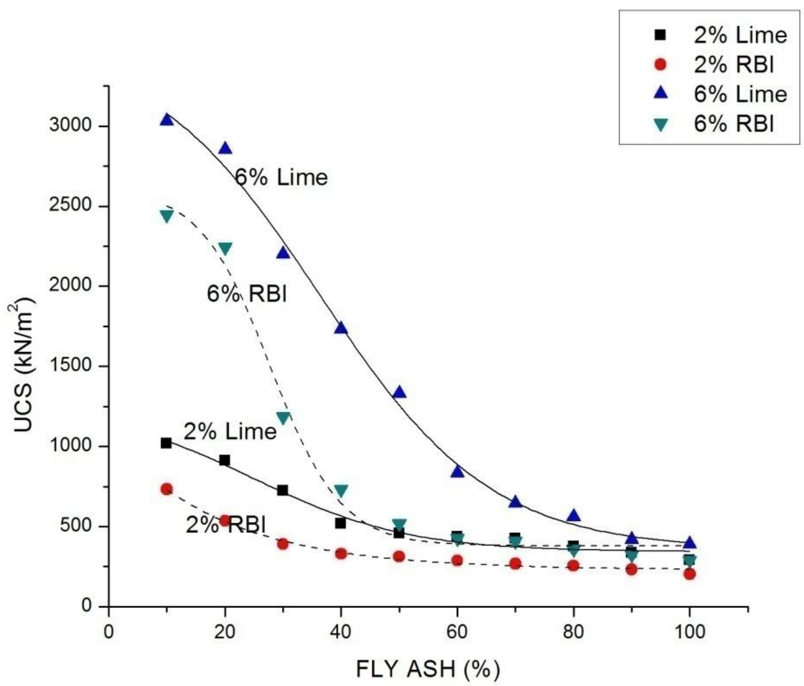

Fig4.35. Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 7 days curing

4.5.2 Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 7 days curing:

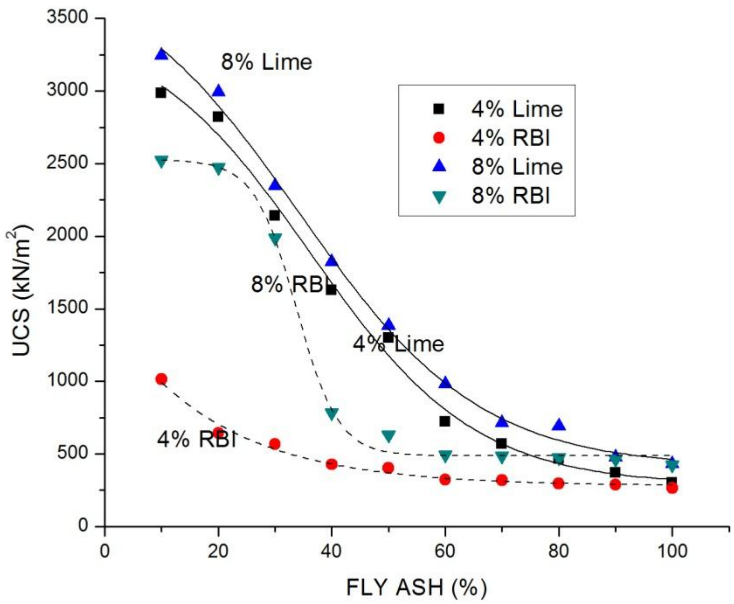

Fig4.36. Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 7 days curing

4.5.3 Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 14 days curing:

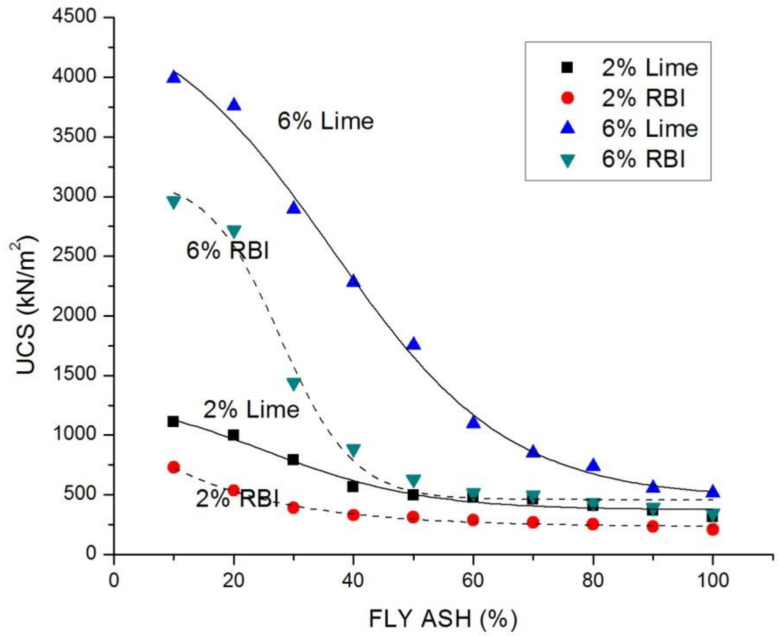

Fig4.37. Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 14 days curing

4.5.4 Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 14 days curing:

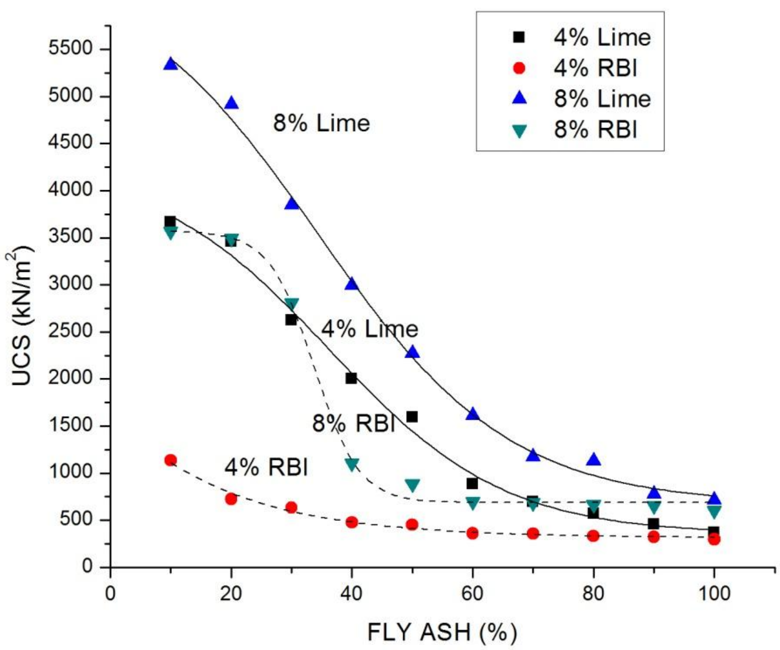

Fig4.38. Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 14 days curing

4.5.5 Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 28 days curing:

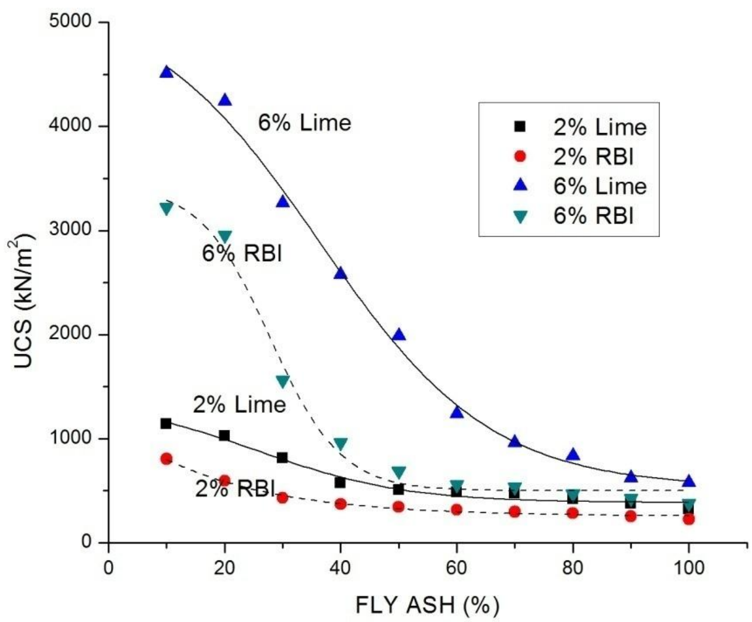

Fig4.39. Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 28 days curing

4.5.6 Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 28 days curing:

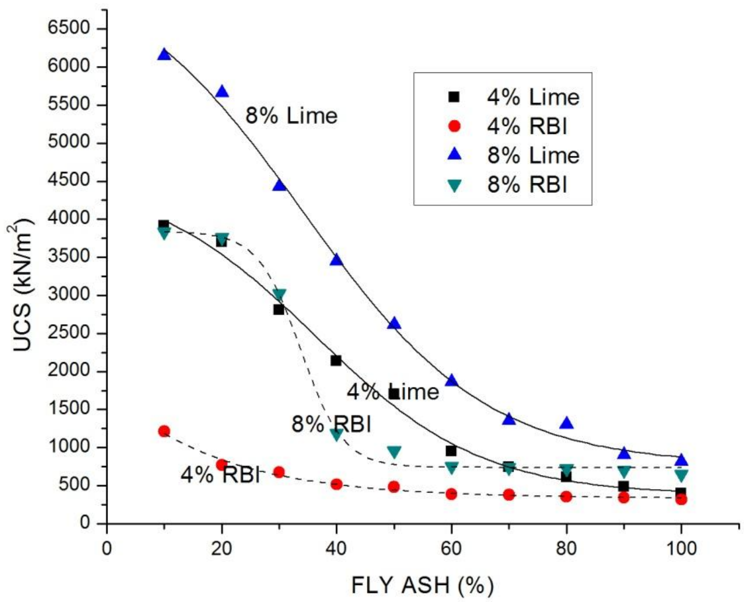

Fig4.40. Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 28 days curing

4.5.7 Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 60 days curing:

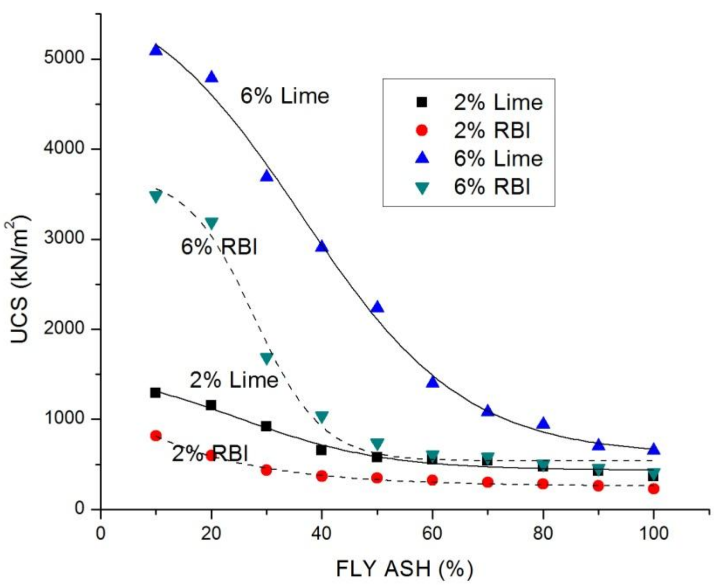

Fig4.41. Comparison of UCS value for RBI and Lime at 2% and 6% for different composition of BFS and fly ash for 60 days curing

4.5.8 Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 60 days curing:

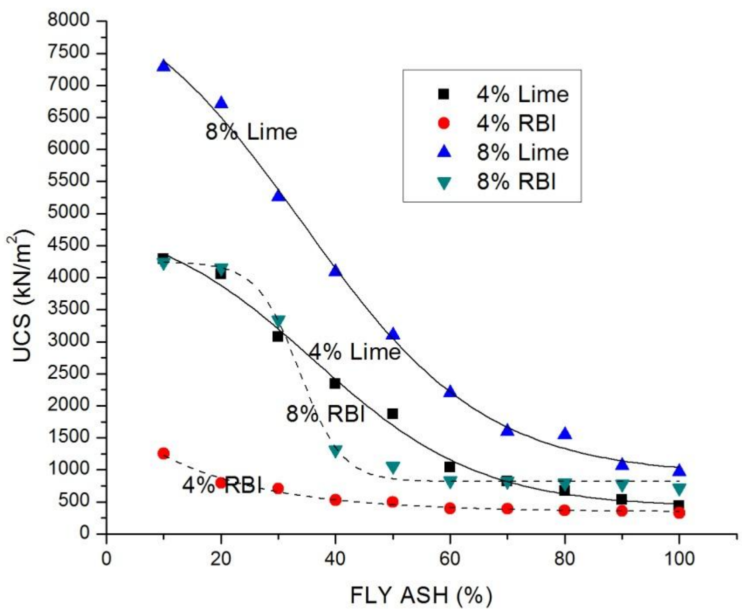

Fig4.42. Comparison of UCS value for RBI and Lime at 4% and 8% for different composition of BFS and fly ash for 60 days curing

CHAPTER 5

CONCLUSION

The present project can serve as an effective method to utilize industrial wastes fly ash and BFS in the construction of road and highway. Based on results of standard proctor test and UCS test the following conclusions are drawn. The conclusions are based on the tests carried out on samples selected for study. The conclusions cannot be generated. The users are advised to conduct separate tests to determine the unconfined strength of stabilized samples of a particular site.

1. The OMC of BFS and fly ash mixes increases with increase in percentage of fly ash.
2. The MDD of BFS and fly ash mixes decreases with increase in percentage of fly ash.
3. The OMC of BFS and fly ash mixes decreases with increase in percentage of BFS.
4. The MDD of BFS and fly ash mixes increases with increase in percentage of BFS.
5. The unconfined compressive strength of stabilized samples increases with increase in percentage of lime and RBI grade 81. The rate of increase is more in case of lime.
6. The unconfined compressive strength of stabilized samples increases with increase in days of curing.
7. The unconfined compressive strength of stabilized samples is more for lime than RBI grade 81 after 7, 14, 28 and 60 days of curing.
8. The unconfined compressive strength of stabilized samples increases with increase in blast furnace slag (BFS) percentage i.e. 90% BFS + 10% fly ash has highest strength and 100% fly ash has lowest strength.

Thus the present analysis and results can serve the purpose of using BFS and fly ash in road construction. Hence the blast furnace slag and fly ash stabilized by lime and RBI Grade 81 can be used effectively in construction of road.

CHAPTER 6
REFERENCES

1. Christoulas,S., Kollias,S. and Marsellos, N. (1983), The use of fly-ash in road construction in Greece, intervention in the 17th World Road Congress, Sydney.
2. Ghosh, R K, Chaddha, L.R. Pant, C.S. and Sharma, R.K. (1973)-"Stabilization of Alluvial Soil with Lime and Fly Ash" J. Indian Roads Congress, 35:1-23.
3. Gokhale, K V G K and Prasad, G (1975)-"Mineralogical Changes and Strength Development in Soil-Lime-Fly Ash Stabilization". Proc. Symposium on Recent Developments in the Analysis of Soil Behavior and Their Application to Geotechnical Structures. University of New South Wales, Kensington, N.S.W. Australia, 439-449.
4. Hilmi, A. and Aysen M. (2006), Analyses and design of a stabilized Fly ash as Pavement base material, *Fuel*, **85**(16), 2359-2370.
5. Kolias S., Karahalios A. (2005), Analytical design of pavements incorporating a capping layer of stabilized soil with high calcium fly ash and or cement, Proceedings of the 1st Conference for the Utilization of Industrial By products in Building Construction,Thessaloniki, 37-46.
6. Linn, M.D. and Symons M.G. (1988), Lime-Fly ash stabilisation of fine grained soils, *Australian Road Research*, **18**(3), 53-161.
7. Mouratidis A.(2004), Stabilization of pavements with fly-ash, Proceedings of the Conference on Use of industrial by-products in road construction, Thessaloniki, 47-57.
8. Prashanth J.P., (1998)"Evaluation of the Properties of Fly Ash for its Use in Geotechnical Applications".PhD Thesis, IISC. Bangalore.
9. Sherwood, P.T., Alternative materials in road construction, Thomas Telford Publications, London, 1995.
10. Tsohos G. (2004), Utilization of by products and alternative materials in road construction, Proceedings of Conference on Use of industrial by-products in road construction,Thessaloniki, 7-15.